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THE WHITE RAT AND THE MAZE PROBLEM

I. THE INTRODUCTION OF A VISUAL CONTROL

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WITH EIGHT FIGURES

Small[1] was the first to emphasize the importance of the kinaesthetic sensations in the life of the rat, while Professor Watson,[2] by eliminating the senses one by one, showed that in learning the maze, at least, senses other than the kinaesthetic and tactual can easily be dispensed with. The natural conclusion was drawn that in such problems these animals use vision, hearing, olfaction, etc., but slightly if at all.

The recognition of the functional value of the kinaesthetic sensations and the dominant part which they play in such a bit of learning as this has been of the greatest possible value. The question is immediately raised, however, of what intrinsic value are eyes, ears, etc., if not for learning. Or, the question might be put in this way: Is this motor co-ordination and the mode of learning entirely different from those other habits which the rat acquires naturally in its usual environment.

Professor Watson himself anticipated further work when he says, " We have supported everywhere the negative conclusions of Small. We, no more than he, offer positive evidence that the kinaesthetic are the only necessary factors in the maze association. Both of us alike used the method of elimination . . . We feel that we are now in a position to begin the study of the positive aspects of the problems offered by the behavior of the rat in forming the maze association."[3]

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[1] SMALL, W. S. Development of the Young White Rat. *Am. Jour. Psychol.*, vol. 11, p. 234. 1899.

[2] WATSON, J. B. Kinaesthetic and Organic Sensations. *Psychol. Rev. Mon. Sup.*, vol. 8, no. 2. 1907.

It was this positive aspect of the situation which formed the basis for this study. Our contention was that other senses might enter into the learning of such a problem and modify it. We believed that the true path and the false in the maze might be made to differ so in brightness, in olfactory qualities, in tactual values, etc., as to affect the establishment of the habit. Our object was to find out if the learning process was thus affected and in what particular ways. The first experiments were concerned with an attempt to introduce sight as a control in the formation of this habit. The maze as ordinarily constructed and as used by Professor Watson is all of wood and of one color and is not favorable for the use of vision. The sides of the runways are high enough to prevent any visual help from outside unless from above. It has been shown many times that human subjects under such conditions find it difficult to obtain or to use visual clues. Ours was not the first attempt to introduce visual control in the maze. Others had tried the same thing in different ways but the stimuli which they used were ineffective and the investigators did not carry their experiments far enough to make any final statements. Although so much has been done with rats the proof of their ability to use vision in any exact way was not very conclusive.

PREVIOUS WORK

The previous lines of experimental evidence as to the effectiveness of vision are several: first, the comparison of the time of learning and speed in running of normal rats trained and tested in the dark and light respectively; second, a comparison in the same respects of normal and blind animals.

Professor Watson based his conclusions, as to the uselessness of vision in the maze, upon the fact that normal rats trained in the light could run the maze as quickly in the dark; that normal rats could learn the maze in the dark and acquire as rapid speed as in the light; and that blind rats could learn the maze and run it with a speed equal to that of their normal companions. It has been shown by others that it is scarcely fair, in such a situation, to make speed the sole criterion of the learning process.

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[3] Ibid, p. 96.

It must also be remembered that many experimenters who have attacked this problem fail to separate in their detailed results and conclusions the typical learning process, which is shown chiefly in the first few trials, and the perfecting of the automatism, the acquisition of speed, which follows. Possibly Professor Watson's work may bear this criticism.

The third line of evidence comes from attempts to introduce visual clues at critical points in the maze. Small fixed colored posts at such places and also varied the direction of the light which fell upon the maze. He concluded that the use of vision was not shown by any discrimination or recognition.[4] Miss Allen marked the path for another rodent, the guinea pig, with colored cards but her results were negative.[5] Professor Watson, in the case of one rat, used colored lights with no perceptible effect.[6] All of these objects were stationary. It is possible that moving objects might have been better. Rats are hypermetropic and such animals may well fail to respond to near objects in any discriminating way.

The fourth form of attack upon the visual powers of these animals consists in observations of the animals and experiments with them in the dark and in the light respectively and noting the amount of activity and the accuracy of movement. Opinions differ slightly here. Slonaker shows in his studies of the activity of the white rat that its greatest period is during the night, beginning with the first shadows of afternoon. He says that the average distance traveled is five miles per night as against one-tenth of a mile per day and concludes that light normally does have an influence upon the animal's activity.[7] A few of Yerkes' dancers seemed somewhat disturbed by tests in the darkness.[8] Miss Allen found that her guinea pigs made more random movements in the darkness than in the light.[9] So far as I know no one has followed this lead further. It would be an interesting bit of experimental work.

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[4] Op. cit.

[5] ALLEN, JESSIE. Association in the Guinea Pig. *Jour. Comp. Neur. and Psychol.*, vol. 14. 1904.

[6] Op. cit., p. 43.

[7] SLONAKER, J. P. The Normal Activity of the White Rat at Different Ages. *Jour. Comp. Neur. and Psychol.*, vol. 17, p. 342. 1907.

[8] YERKES, R. M. The Dancing Mouse. P. 189. 1907.

[9] Op. cit.

The fifth line of proof lies in the comparison of blind and normal animals as to their accuracy of movement. In the experiments reported in Orientation in the Maze where, by means of a removable section, the maze could be lengthened and shortened there was a blind animal which had trouble with turns which the normal rats made correctly. The authors say of some other (normal) animals, " Since two out of the eight animals made eight out of the nine unquestioned immediate orientations we are willing to admit the possibility of the use of distance sense data in their cases."[10] Miss Richardson in some jumping tests with rats, where both direction and distance of the jump were varied independently of each other and also varied from habitually established norms, concluded that the visual stimulus furnished a control as to the direction of the jump but failed to afford any accommodation to changes in distance. Concerning some tests with problem boxes, she says they afforded no conclusive evidence as to the functioning of visual impulses. " The lack of vision, however, was disadvantageous in proportion as the problem demanded finely coordinated and narrowly localized movements."[11]

The sixth method of investigation is more directly concerned with the sense itself. The Watsons concluded from experiments with spectral lights that there is good if not conclusive evidence, since green was not used, that the responses were made to differences in intensity and not quality. Similarly Miss Weidensall showed in a critique of discrimination that in experiments with black and white the white was twice as effective as the black and that in most discrimination experiments with two objects only one of the objects may have any regulative control, the other being neglected.

The use of sight by some animals, as birds and monkeys, is admitted in connection with such problems but we have confined this report to rodents whose vision is of a common type.

The following views are held as to the place of vision in the labyrinth problem: (a) The control is kinaesthetic *par excellence*, coupled probably with tactual and static and possibly with organic sensations; (b) Vision may have a tonic stimulating effect or it may serve merely for general orientation; (c) Vision is not for perceptual purposes—"The rat does not hang his associations upon gross and obvious (visual) objects;" (d) Sight may lessen random movements; (e) It may give general direction if not accurate distance; (f) Vision may even be a hindrance in such problems.

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[10] Carr, Harvey, and Watson, J. B. Orientation in the White Rat. *Jour. Comp. Neur. and Psychol.*, vol. 18, p. 27. 1908.

[11] Richardson, Florence. A Study of the Sensory Control in the Rat. *Psychol. Rev. Mon. Sup.*, vol. 12. 1910.

In a previous paper[12] facts have been given which show that the rat's vision is weak. It may be possible that a rat does not discriminate stationary objects and it is probable that brightness is the most effective factor. In this work, however, there was no attempt made to substantiate such opinions or to evaluate the visual sense. The only interest lay in the attempt to see whether vision could not be introduced into the labyrinth problem as a control and if this could be done then to determine what was its effect upon the establishment of the automatism.

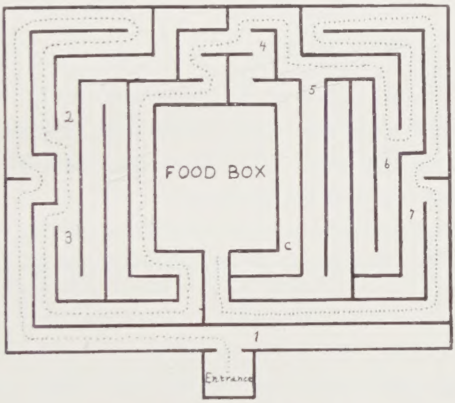

FIG. 1. Plan of maze

APPARATUS AND MODE OF EXPERIMENTATION

The maze used was the modified Hampton Court Maze which Professor Watson describes in "Kinaesthetic and Organic Sensations." [13] Indeed it was one of the same mazes which he used in his experiments. The only change in the construction was the blocking of pathway "C" at the farther end to make it a blind alley instead of a longer way around (Fig. 1). The essential difference, however, was the fact that the true pathways and the blind alleys were made to differ as far as possible in brightness. Black cardboard lined and covered the one and a very white paper lined the other. In the later experiments black and white enamel paint was used on the floor and sides while black cardboard covered the top of the black pathway.

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[12] VINCENT, S. B. The Mammalian Eye. *Jour. of Animal Behavior,* vol. 2, no. 4, pp. 249-255. 1912.

[13] For detailed description see "Kinaesthetic and Organic Sensations," op. cit., p. 16-18.

The problem box for the discrimination tests was a pasteboard box 12′ x 12′ x 9′, with round tubes inserted at the floor level in opposite sides. One tube was white, with white oiled paper pasted in the upper third to increase the brightness, the other tube was black. The tubes were not straight but were bent in the middle at right angles to prevent any entering light from the end of the open tube from giving a clue. Only the tube of the brightness for which the animal was being trained remained open at the end. The box was turned in an irregular order to prevent choice by position.

The only stimulus to the activity was the reward of food at the completion of a successful run in the maze or the choice of the right exit in the problem box. Five animals usually constituted a group.

Some records were first made upon the maze as it originally stood with walls and floor of unpainted pine. A group of untrained rats was given 50 trials covering a period of 18 days. These rats were then taken over to the problem box where they were given 50 trials. Then another group of rats which had previously been given 50 trials on the problem box was put in the maze for 50 trials. Ten trials a day were given in the problem box, but on the maze only 3. These records are referred to as the normal records and furnish the standard for comparison.

The maze was then made black and white, the true path black (see dotted line, Fig. 1) and the blind alleys white. Two other groups of rats learned both it and the problem box in alternation as above. This maze is sometimes spoken of as the black maze.

The third change consisted in making the true path white and the *cul de sacs* black and using two new groups of animals in the manner described above. This maze is occasionally referred to as the white maze.

In brief the experiments upon which this discussion is based are as follows:

1. Normal maze records—(a) rats trained; (b) rats untrained; (c) discrimination experiment for (a); (d) discrimination experiment for (b).
2. Black-white maze records, true path black—(a) rats trained; (b) rats untrained; (c) discrimination experiment for (a); (d) discrimination experiment for (b).
3. Black-white maze records, true path white—(a) rats trained; (b) rats untrained; (c) discrimination experiment for (a); (d) discrimination experiment for (b).

The reason for the use of the two pieces of apparatus was this: After the first group of animals had learned the black and white maze we wished to see whether it was really brightness to which the animals were reacting. The other experiment—the box with the black and white exits—was devised, therefore, to see whether the brightness experience carried over. Then the suggestion arose that the differences which were seen in the conduct of the rats might not be due to brightness alone but that some of the changed results might be a general effect of training. To meet this criticism not only were the experiments doubled by the use of both maze and box, but groups of animals trained upon the box afterward learned the maze and animals trained upon the maze learned the box. In order to make the normal group comparable the training also had to be included in their case although the maze was uniform in brightness.

It may be objected that the contact values of the two media, paper and cardboard, used in the first experiments differed and that the air pressure, sound qualities, etc., were not the same in the two paths. The work will have to face that criticism. The training tests upon the problem box and the succeeding experiments upon it seemed to show, however, that it was really brightness to which the animals were reacting. The six blind animals used upon the black-white maze furnished a further control. If there were other sensory elements fused with vision it does not affect the value of the experiment since this is normally true and since it was the visual element which was the variable one.

The tables submitted show only the time of a total reaction and the errors. Leaving the true path, entering a *cul de sac*, was counted as one error. Returns could not be counted as errors since part of the maze was covered. For the same reason we can say nothing about the total distance traversed. All of the tables upon which this discussion is based would gladly be given but it is impossible within the limits of this paper. The results will be shown by means of graphs upon which the discussion will be based and only such other additional data will be given as is necessary.

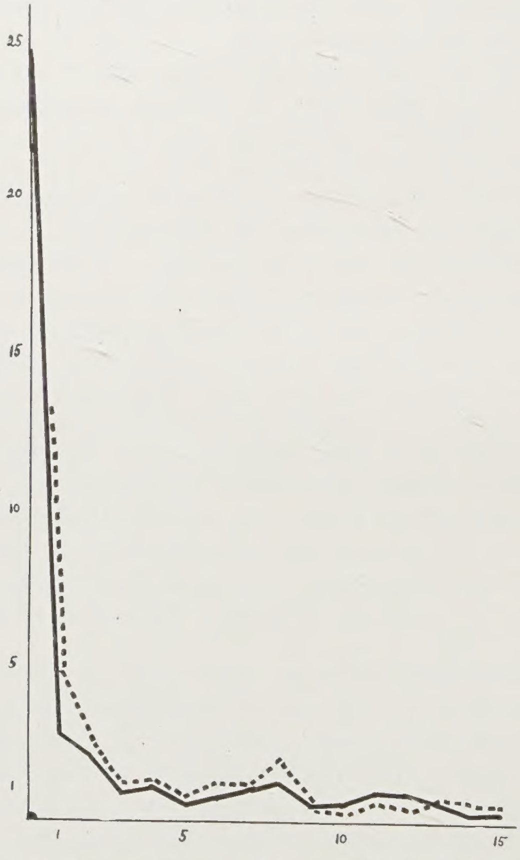

FIG. 2. Learning curves of 10 rats on the normal maze
——— Time, - - - - - - - - Errors

Four months' work was put upon this problem in 1907. Nothing more was attempted until it was resumed in 1910. None of the first experimentation is reported here, since it was all repeated in the later series under stricter control and with similar results.

NORMAL MAZE

There is no need in this place of giving a long description of the general behavior or giving the individual details of the experimentation with the groups of rats in the normal maze. The conduct differed in no respect from that noted by so many others. The curve of learning may be seen in Fig. 2. The description of the mode of plotting this curve may be found in my monograph on the tactile hair.[14] The actual time and the number of errors for the first 10 trials are given in Table 1. These records are made from the combined records of two groups of animals, one of which had been previously trained upon a black-white discrimination box. As this training proved to have so little effect upon the subsequent maze record these pages will not be burdened with the numerical results.

TABLE 1

TIME AND ERROR RECORDS, FIRST TEN TRIALS, ON NORMAL AND BLACK-WHITE MAZES

	Time		Errors	
Trial	Normal Maze	Black-white Maze	Normal Maze	Black-white Maze
1	1804 sec.	1342 sec.	14.9	7.5
2	966	413	11.9	4.3
3	542	254	10.4	3.
4	847	211	7.4	3.
5	233	98	4.1	1.6
6	193	72	3.5	1.
7	63	37	1.6	.5
8	49	48	1.4	.2
9	37	54	1.5	.5
10	33	39	1.1	.4

The training upon the box, on the whole, seemed slightly disadvantageous to the group of animals which later learned the original maze. There was not so high a degree of accuracy as evidenced by the number of errors and the average time taken per trial was longer than that of the other group which had had no training. To account for this is not difficult when we consider that the problems are distinctly different. In the one case there is an immediate reaction, in time too brief to be taken, to a situation which offers but two alternatives and in which brightness is the determining factor. In the other case there is a devious way to learn which involves many turns and the possibility of many false turns. The final escape to food takes a time which varies from two hours per trial at the beginning to ten seconds when the problem is learned. The habits set up by the brightness contrast, whether depending upon discrimination or not, clearly cannot be carried over advantageously to a situation where the contrast does not exist. It may easily be conceived also that the motor habits involved in the simpler reactions described above for the problem box which bring the rat immediately to the presence of its food might be disastrous and delay the acquisition of a reaction depending upon the co-ordination of a long series of acts and extending over a considerable period of time.

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[14] VINCENT, S. B. The Function of the Vibrissae in the Behavior of the White Rat. *Behavior Mon.*, vol. 1, no. 5, p. 15. 1912.

As the learning of this maze has been so fully and freely discussed before all mention of it will be neglected here and any facts of interest concerning it will be brought out in the comparison of the two mazes which will follow later.

BLACK AND WHITE MAZE

The outcome of the tests on the black and white maze was noticeably unlike that of the normal maze. The differences were seen in the behavior of the animals and appear in the numerical results and the graphs plotted from them. They were confirmed and checked by the data furnished by the blind animals and by the facts brought out in the box experiments.

Success in such a problem has several measures: (a) the time taken relative to the total distance, i.e., speed; (b) the number and distribution of the errors, i.e., accuracy; (c) the time of learning, i.e., the number of trials in learning; (d) the surplus values of time and errors; (e) the rate of elimination, i.e., distribution of effort; (f) the form of the learning curve—a picture which reveals some of the complex relationships existing among the various factors. In this paper the burden of proof will be put upon accuracy and speed, since it was in these two respects that the greatest divergence was seen. The other criteria, however, will not be entirely neglected.

In the interest of clearness as well as of time and space, the results from the four groups of animals, trained and untrained, for the black and for the white maze, will be combined and presented as a whole. The differences were unessential. Any evidence of training being carried over from the box to the black-white maze was so slight that it may be neglected. This is due, doubtless, to the fact that the two problems were so dissimilar and that the time on the box was so brief. On the contrary, there was decided evidence of the effect of training in animals which went from the black-white maze to the box but that will be mentioned in another connection. The results also, when the true path was white and when it was black, agreed entirely in the essential details and hence they may be massed. The minor differences will be used only by way of explanation or illustration.

SPEED

Speed is time as measured by the distance traversed. In this case it is impossible to state the total distance since the returns, in the part of the maze which was covered cannot be counted. However, some evidence can be offered. One of the first lines of proof is the observed conduct of the animals.

The behavior in the black-white maze was very unlike that in the normal maze. In the beginning trials there was less activity, more sluggishness of movement, fewer errors, yet slow runs. Time and again I find in my notes such expressions as: " Slow start." "A very slow walk around although without error." " Very little rapid running." " Slow movement compared with normal maze." " No running and little sniffing at food-box or anywhere else." " Little running but much actual sitting still." " Few errors but little running." " Do not seem at all frightened or curious." " Do not apparently use covered ways as places of refuge." " Errors do not seem attractive and there is no blind running which would make the animals blunder into errors." There was more hesitation seen in these rats. Even long after the problem was learned they slowed up or wavered in their running when they came to a *cul de sac*. Some typical records, where every move which could be seen was entered with the time which it took, may serve to indicate the lesser activity better than a general description.

First Two Records of Rat "1"

May 10th and 11th:
  1st trial:
    To first corner and back—10 sec.
    About entrance 55 sec.
    To first corner 10 sec.
    Here 2 min. 30 sec.
    Home—remains 9 min. 30 sec.
    First corner 15 sec.

Second corner 30 sec.
Reaches error "2" in 15 sec.*
Reaches error "3" in 5 sec.
Stays here 1 min. 15 sec.
Reaches food box 15 sec.
Reaches error "4" 15 sec.
Reaches error "4" 15 sec.
Reaches error "6" 11 sec.
Reaches error "7" 20 sec.
Back to "6" 1 min.
Back to "4" 10 sec.
Back to food box 10 sec.
Returns to "4" 30 sec.
Returns to "6" 20 sec.
On to "7" 1 min. 45 sec.
Back to "6", here 5 min. 15 sec.
Back to "4" 30 sec.
In "4" and out. Sits here 30 sec.
On to "6" 15 sec.
On to "7" 1 min.
Sits at "7" 3 min. 30 sec.
In "7" and out 30 sec.
Sits here 7 min.
On to food box 15 sec.
Total time 40 min. 22.6 sec.
Errors 2.

2nd trial, rat "1":
Slow start.
Reaches 2nd corner 5 sec.
Reaches error "2" 10 sec.
In and out error "2" 20 sec.
In and out error "3" 10 sec.
Reaches food box 30 sec.
Reaches error "4" 15 sec.
In and out "4" 30 sec.
Reaches "6" 5 sec. Here 20 sec.
On a short way 30 sec.
Returns to "6". Here 15 sec.
Back to "3" 1 min. 30 sec.
Returns to food box and back to "3" 1 min.
To food box. Here 3 min. 30 sec.
Back to "3". Here 30 sec.
To food box 1 min.
To "4" 15 sec.
Reaches "6" 15 sec. Here 15 sec.
In and out "6" 30 sec.
In alley near 1 min. 45 sec.
Back to "6". Here 45 sec.
Back to "4", to food box, to "3", 30 sec.
Back to "2". Here 1 min.
Back to food box 30 sec. Here 9 min. 30 sec.
On to "4", back to food box 30 sec.
On to "4", back to food box 15 sec.
On to "4", in and out 1 min.
On to "6" 15 sec.
On to "7" 45 sec.
On to food box 15 sec.
Total time 29 min.
Errors 4.

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* "2", "3", etc., are the numbers of the blind alleys in the Maze. See Fig. 1.

These individual records show the type of behavior described above, which clearly is not like that seen in the normal maze in the first and second trials. There, the rats cover three or four times the distance and make twice the number of errors. Here, the total distance traversed in the true path in trial one was 93 ft., making the rate about 2 ft. per minute. It is true that the rats were not moving all of the time but neither were the rats in the normal maze although they are far more active. The total distance covered in the true path in the second trial was 135 ft. The rate, therefore, was but little less than 5 ft. per minute. If the activity had been evenly distributed over the maze, this rat, in its first trial, should have been in the false path 18 minutes and in its second trial 13 minutes.

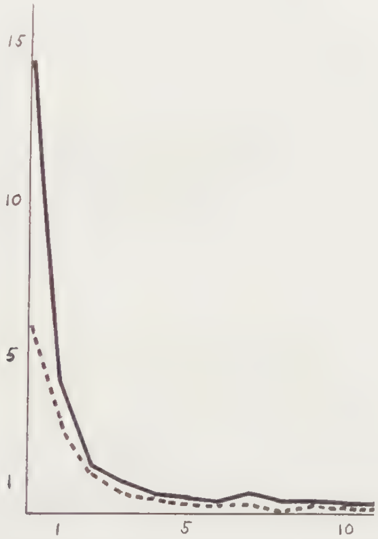

FIG. 3. Learning curves of 20 rats on the black-white maze
———— Time, - - - - - - - - Errors

From the figures of the rats in the normal maze I took those of the rat whose time and error records most nearly approached the average and computed the total distance, etc., for the first and second trials in the same way as above. This rat's time was a little low, so the speed is probably a little high for the first trial. The first trial showed a total distance covered of 313 ft. of which 190 ft. was in the true path and 123 ft. was in the blind alleys. The average speed for the entire distance was a little over 15 ft. per minute. The total distance for the second trial was 184 ft. of which 106 ft. was in the true path and 78 ft. in the *cul de sacs*. The speed then was 27 ft. per minute. Notice the distribution of the activity in this maze and compare it with that of the black-white maze above.

This slowness might be made more evident by another illustration. The average time of the first trial made without error for the rats on the normal maze was 45 sec. The average time of the 20 rats on the black-white maze for the same errorless trip was 122 sec. It took the latter group over four times as long. Returns were not counted in either case but so far as I can tell they were very few and fairly comparable.

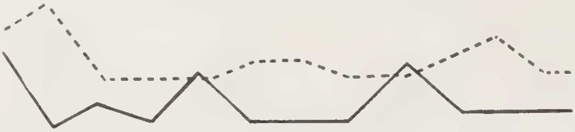

FIG. 4. Time curves for black-white and normal mazes, last 10 trials
——— Normal, - - - - - - - - Black-white

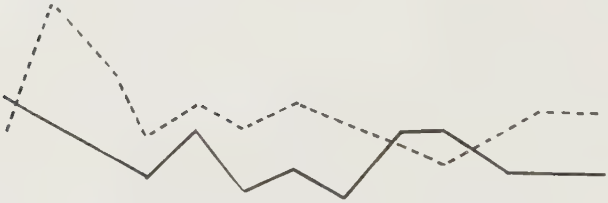

FIG. 5. Error curve for black-white and normal mazes, last 10 trials
——— Normal, - - - - - - - - Black-white

But besides these individual records there are the combined group averages. The numerical data for the first ten trials has already been referred to (Table 1). The curves plotted reveal the same characteristics (Fig. 3). The time curve begins much lower in the black-white maze but that is because of the fewer number of errors which decreases the total distance of the run. These curves do not show the actual number of trials nor the exact average time for any particular trial. The first two-thirds of the distance shows the learning process, the last third an automatism. The ordinary curve where one trial is the unit resembles this in main outlines but the automatic period is greatly extended. Curves plotted with one minute as the unit of time do not reveal really significant fluctuations since the maze can be run in ten seconds. An increase of ten or twenty seconds scarcely shows on the curve, although the rats are taking two or three times longer to run. The end of a graph, in which one trial is the unit, has been magnified and the last ten runs of the fifty are revealed in a more significant fashion (Figs. 4 and 5). The time curve for the normal maze is considerably lower than that for the black-white maze. The records show that the average speed of the last five trials of the rats in the normal maze is ten seconds better than the speed of the rats in the black-white maze for the corresponding trials.

Thus the evidence, from the behavior notes, from typical individuals, from the average speed in the first trials without error, from the actual speed of individual animals in the true path, from the numerical results and plotted curves, confirms the original assertion. Rats in the black-white maze, in experiments continued long past the learning period, maintain a slower speed than rats in the normal maze. The significance or cause of this will be discussed later. We will now consider the criterion of accuracy.

ACCURACY

One of the first things to attract the attention of the observer who was watching these experiments day by day was the very few errors which were made. No one who had had any experience with other mazes could fail to be impressed by it. A number of animals made their way around several times without error on the second trial. They went slowly, to be sure, but accurately. There were no signs of marked avoidance but neither was there any evidence of direct discrimination. Slow as these animals were they did not enter many *cul de sacs*. If a rat by chance entered one of these blind alleys it did not seem in any hurry to get out but neither did it linger in it. One rather expected that the rats would tend to hide or tarry in the side-paths, especially when the covered ways were the *cul de sacs*.

The accuracy was apparent from the very beginning and was not a virtue of slow growth. Whatever influence was at work it was there from the first. The rats on the normal maze made an average of 14.9 errors the first trial while those on the black-white maze made only half as many, 7.5.

Notice the difference in the initial height of the error curves of the two mazes (Figs. 2 and 3). The error curve of the black-white maze is not like any error curve made for a normal maze and it is a direct expression of the accuracy. The time curve which accompanies it, as has been said, is low because of the fewer errors and not because of more rapid speed.

There is a great decrease in total as well as in beginning errors from the mark set by the normal maze. The latter maze has to its credit an average of 66.6 errors per animal or 1.48 per trial for each rat while the black-white maze gives only 35.6 errors

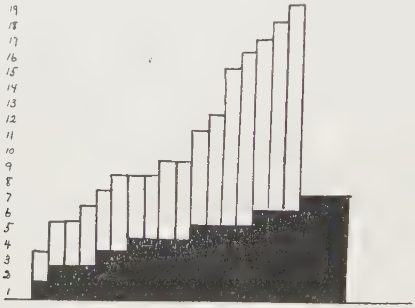

Fig. 6. Graph showing the point at which the animals made their first trial without error. Each vertical bar represents an animal. The black represents those of the black-white maze. This is superimposed upon the white, which represents the animals in the normal maze.

per animal or .8 per trial. The accuracy is nearly twice as great in the black-white maze.

One would naturally expect then, what really is the case, that the error curve for the black-white maze (Fig. 3) would reach its lowest level much sooner than the error curve for the other maze—that the automatism would be more quickly established. The figures show that the rats on the black-white maze made their average first trip without error on the 4.2 trial but the average for this trip on the normal maze was 8.5. If we take the first ten trials and compare them we find that the rats in the black-white maze have an average of 4.2 perfect trips to their credit while the normal maze has only half that number, 2. The graph seen in Fig. 6 is made from the records of 20 animals in the black-white maze and of 17 in the normal maze. It shows the trial at which the zero point was reached and the number making it at each point. It is perhaps more striking than the ordinary error curve.

If the errors are so few in the beginning, if the co-ordination is acquired so quickly, why is it that there is not a greater difference in the total errors ? This is a question which requires an answer. The answer is that the final accuracy is less. See the curves, Figs. 2, 3 and 5. The normal error curve is regularly at the end of 50 trials below the black-white. What the causes are which produce this greater final variability is a question for our future inquiry. The three main points to be emphasized here are the few beginning errors, the rapid drop to the zero point and the persistence of errors to the very end.

SURPLUS TIME AND RATE OF ELIMINATION OF TIME AND ERRORS

Professor Carr argues at length for the value of the rate of elimination of surplus time and errors as one of the elemental components of the learning curve which varies independently from the other components.[15] The curves which show elimination in the experiments here reported are seen in Fig. 7. The rate of elimination is very similar in the two mazes. There are, however, some points of contrast.

The time curve for the normal groups exhibits a fairly steady rate of decline to the 24th trial. Here the final limit is reached, .4%. The time curve for the black-white group reaches its final limit of 1.8% on the 9th trial. It then follows the same course as the curve for the normal maze but with greater variability. The curve for the black-white maze reaches its level much sooner but cannot maintain it with the same constancy; neither can it reach, in the limits of the experiment, the same low level which the normal curve so easily reaches and maintains.

The error curve of the black-white maze indicates a much quicker rate of elimination than that of the normal maze. There is a steady drop till the 6th trial. From this point on there is only 6% of the errors left to eliminate. It will be remembered that the black-white maze had fewer errors to eliminate at the beginning. From the 6th trial on, however, the rate of elimination is below that of the normal maze. For the twenty succeeding trials the average is slightly above 6% and is only 1% less than this at the end.

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[15] Hicks, Vinnie, and Carr, H. A. Human Reactions in the Maze. *Jour. of Animal Behavior,* vol. 2, no. 2, p. 98. 1912.

The errors are eliminated more slowly in the normal maze. This curve does not reach the 6% level until the eleventh trial.

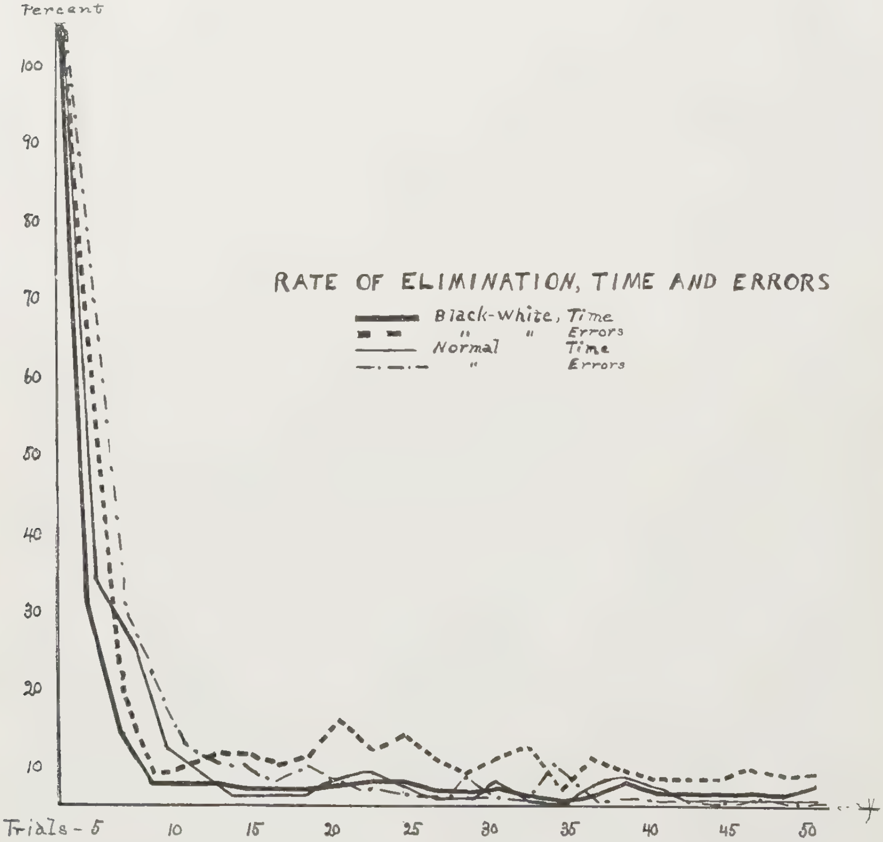

FIG. 7. Curves showing the rate of time and error elimination in the black-white and the normal mazes

From here on, however, there is a regular decline until, in the eighteenth trial, there is only 1% left to be eliminated. The curve wavers above and below 1% but this is practically the final level. The black-white maze has five times as much left to eliminate at the end as the normal maze.

BRIGHTNESS

But it may be argued that although the reactions of the rats in the black-white maze differ from those made in the normal maze in respect to speed and accuracy, the contributing cause may not have been the brightness of the runways. In reply it can only be said that no other difference can be seen in the experimental conditions. The maze was the same in every experiment and it stood in the same place. The animals were from the same breeding cages, were given the same care and were used by the same person throughout. Tests to prove that it was the brightness factor, however, were introduced.

The blind animals furnished the best means of control. These animals were of the same original stock as the others and during the entire period of experimentation were kept in the cage with the others. They ran the maze daily with the other rats. They were put through the box problem but could not learn this as the rats with vision did. When taken over to the maze they behaved just as the blind rats in the normal maze behave. The learning curve for these rats has been plotted and may be seen in Fig. 8. Compare this curve with that made for the rats in the normal maze, Fig. 2, and see how nearly identical they are. Neither resembles at all the curve for the black-white maze, Fig. 3. These blind rats were in good physical condition, active and strong, and the only observable difference from their companions was in their lack of vision. Is not the conclusion fair that the contrast in behavior and the different numerical results of the two groups of animals used in this part of the experiment were due to the visual situation in the maze?

The second control was the use of the problem box. Rats taken from the box over to the normal maze showed no favorable effect of general training. The training if anything resulted unfavorably. The reasons have already been given. Rats trained on the box when taken to the black-white maze exhibited no unfavorable effects of training but gave some slight indications that the brightness experience had been an aid. The slightness of this effect was probably due to the differences in the essential nature of the two problems and the briefness of the time in which the animals were in the box.

From the black-white maze to the box, however, the effect was different. The experience certainly did carry over. The number of trials in learning was one-third less and the total number of errors was reduced in the same proportion. The brightness situation must have been responsible for these contrasting results. The lengthened period of training on the maze before attempting the problem box may account for its greater effectiveness in this case.

Although the conduct described above was influenced by brightness, may there not have been a preference, either instinctive or acquired, for black or for white? It must be remembered that the animals in the experiments described may have been reacting to one color only regardless of any changes in the maze.

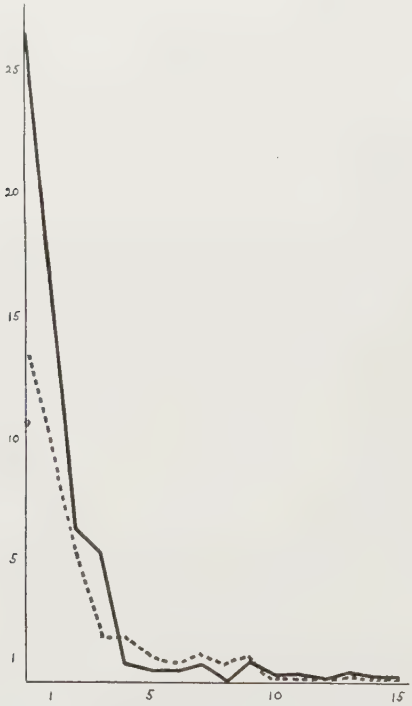

FIG. 8. Curves of the blind rats in the black-white maze
———— Time, - - - - - - - - Errors

We do not think the reactions were due to preference. If they had been, there would have been greater differences between the results of the experiments where the true path was white and those where it was black. The following figures, taken from many others, show the similarity of the conduct in the two cases.

	Black	White
Speed in first 5 trials	8.1 ± 4 min.	7.1 ± 3. min.
Final speed	.36 ± .1 min.	.44 ± .14 min.
Surplus time	46.4 ± 17.6 min.	47.6 ± .16 min.
Errors in first 5 trials	18.4 ± 4.4	16.5 ± 4.6
Total errors	30 ± 6.4	39.2 ± 10.5

There are variations, as will be seen in the above table, but the balance is now on one side, now on the other side of the scale.

If there were a preference for either black or white the observed behavior would have shown it. There would have been a lingering in one path rather than the other, a choosing or avoidance of the covered way, more errors in the one case than the other. There was no observable conduct which would indicate such a preference either for black or for white. There must be some other explanation than that of preference.

It is quite possible, even when it is granted that these results are not due to an instinctive preference, that there may have been a difference in the relative stimulative effectiveness of the black and the white paths. Since the effects of training were the same for both black and white the two groups may be compared directly irrespective of the minor grouping for training. The results are very similar. The differences are slight indeed in comparison with the larger differences which were seen between the black-white and the normal mazes and may be due to chance.

The white true path seems to give a better initial direction for the first trials. The animals constituting this group stayed in the true path more consistently than those of the group where the true path was black. But the black *cul de sacs* proved more attractive in the end, for while following the white path more total and more average errors were made than while following the black. A greater number of trials was also necessary in learning. The white path gave the lowest initial time and the the lowest final time although the total time of the two mazes was about equal. Thus while the white path probably gave a better beginning both in speed and accuracy and the speed as a whole was better, the record for total and final accuracy was less than that of the maze when the true path was black.

CONCLUSIONS

The conclusion seems justified that such a contrast in brightness between two roads is exceedingly effective with these animals as they learn the maze. It gives increased accuracy, as is shown both in initial and total decrease of errors, and in a decrease of total time. So far it seems advantageous, yet there was a final inaccuracy greater than normal and a lesser final speed.

There were no outward signs of discrimination such as marked avoidance, quick reaction, noticeable change of behavior with change of stimulus. There was no lingering in one path or another which might indicate an instinctive preference. There was only a slower, perhaps a more cautious, activity in which random movements were inhibited in both initial and early trials prior to any effects of learning.

If the difference is not due to discrimination, and we have no evidence from the behavior or the nature of the curve as ordinarily interpreted that it is, what has caused the different character of the learning ? All who have worked with animals know that a stimulus may be effective although not discriminated. In such a case as this, where two widely differing degrees of brightness were used, one may have been more directive, more potent, more attractive than the other. Professor Carr suggests the phrase " dominance of a stimulus." This would tend to attract the animal's attention either to the white or to the black pathway.

It was said above that the different behavior was seen " prior to any effect of learning." It must be remembered, however, that such a problem is solved not by one act but by a series of acts and hence there may be learning within the trial itself. If the second trial is influenced by the first, if learning has begun, where did it begin ? Learning the maze is not at all like a single act, jumping a certain distance, for example. In a problem of this kind, which takes so long a time, it clearly may begin in the first attempt. As the animals enter this maze they are in the true path be it black or white. The first error, to the right, is barred almost immediately, probably by kinaesthesis. It is seldom made again except in times of great confusion. The true path includes first, a run to the left half way across the maze, then a turn, and then a clear run across one side. In this side there is the possibility of an error, but not one into which the animal runs headlong. Hence from the very first there is a safe experience of a definite sensory sort which extends over a considerable period of time. Because it is the first experience, because it proves safe, because the animal, on the whole, is more in this path than the other, because his returns are made on this path, these may be some of the reasons why this path proved more potent, more dominant, more directive than the other and indicate one way in which learning may possibly begin.

The term learning needs more careful definition. Certainly there was little evidence of discriminative learning here. If there was any, it must have occurred chiefly within the first trial. This possibility may be referred to in a later paper. The curve showing the rate of elimination of time and errors furnishes a slight indication of learning to use vision in the interval between the fifth and the tenth trials, Fig. 7.

If the mere strength of the visual stimulus was the effective cause of the reinforcement or modification of the usual controls, then we shall have to conclude that the white path was, on the whole, the more dominant one. The entire matter then would hang upon the supposition that the brightness factor in a certain path had the power to hold or compel the attention of the animal.

The time taken per trial depends of course upon the speed and the accuracy. The more errors an animal makes, the more blind alleys he explores, the longer the time per trial. Thus the fewer errors would largely account for the lessened initial time. The contrast between black and white, as will be remembered, was as strong as could be produced. The final inaccuracies might have been due to this contrast effect which persisted to the end and attracted the attention of the rats when they were momentarily distracted and thus led them into errors. The stimulating power of this contrast was no doubt responsible for the late development of the kinaesthetic control. But the slow change, when it did come, from reliance upon vision to the automatism of kinaesthesis left vision free to be caught, to be attracted by these contrasts, and led the animals into errors.

The decrease of final speed might have been due to the greater number of errors, yet this is probably not sufficient to account for the result since the speed was less in cases where there were no errors. The slower speed was caused, perhaps, by a natural hesitation because of the attractiveness of the errors and this was made possible by the slighter kinaesthetic automatism.

Our final conclusion is then that if animals are given two contrasting paths side by side, differing in brightness, the one path may prove more dominant and favor accuracy and because of accuracy a shorter time in the early trials. After the problem is learned, in the slow turning over to kinaesthesis, when attention is freed, these sensory factors may still retain their potency in times of momentary distraction. The result is a less perfect automatism and a slower speed.

PRELIMINARIES TO A STUDY OF COLOR VISION IN THE RING-DOVE *TURTUR RISORIUS*[1]

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At the present moment a thorough study of the visual reactions of a few types of birds and mammals is highly desirable. This paper presents an account of observations on the reactions of the ring-dove in the Watson-Yerkes color vision apparatus. The ring-dove was chosen as a subject because of its easy adaptation to laboratory conditions and its convenient size. It was hoped that it might prove an ideal bird for the intensive study of vision.

As a preparation for the study of color discrimination, the limits of the spectrum, and the stimulating values of various wave-lengths, observations were first made on the response of the bird to achromatic stimuli. The apparatus used throughout the preliminary work here reported was the Watson-Yerkes spectral color vision device, as described in volume one of the Behavior Monographs.[2] A Bausch and Lomb automatic arc lamp was used as a source of light, and a selenium cell, as described in the monograph (pp. 79-81) served as a means of measuring the energy of the stimuli employed. For the simple reaction-box shown as W in figure 7 of the monograph, the box represented in figure 1 of this paper was substituted, and instead of having two reflecting surfaces, M and L of figure 7 above referred to, fixed on the experiment-box and moving laterally with it, three reflecting surfaces were employed. These remained fixed while the experiment-box moved sufficiently to reverse the position of the two photic stimuli.

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[1] This work has been made possible by a grant from the Bache Fund of the National Academy of Arts and Sciences, which enabled the author to complete the construction of a spectral apparatus and install a selenium cell outfit to measure chromatic stimuli. Grateful acknowledgment is made to the trustees of the Fund and to the Committee in charge, for the facilitation of this research.

[2] Yerkes, Robert M., and Watson, John B. Methods of studying vision in animals. *Behavior Monographs*, 1911, vol. 1.

The general apparatus need not be redescribed in detail. The reader who is unfamiliar with it is referred to the above-mentioned monograph and to Watson's more recent book.[3] In brief, it consists of a source of light which, by means of a system of lenses, prisms, and slits, is made to supply chromatic stimuli in any desired quality or intensity. Two stimuli are presented to the subject simultaneously. The position of these stimuli may be reversed at the will of the experimenter. The subject is required to distinguish the stimuli and react differently to the two.

Assuming, now, that the reader has a general knowledge of the mechanism by which the chromatic stimuli are obtained, controlled, and measured, we may consider our method of procedure in its relations to the reaction-box of figure 1. This consists of an entrance chamber (A) in which, at the beginning of a series of observations, the subject is placed by the experimenter, and from which it passes, when the door (D) is raised, into compartment B, which may be designated the discrimination compartment. A sliding partition (M) enables the experimenter to avoid delay because of the unwillingness of the subject to enter B, for by raising the door (D) and drawing M slowly and steadily backward toward the rear of compartment A, the subject may, without disturbance, be compelled to enter the discrimination compartment. Once in B, the subject faces the two stimuli S, S. These are presented either with or without general overhead illumination, and they appear as illuminated surfaces, either chromatic or achromatic, 7 cm. long by 1.8 cm. wide. These two stimuli are separated by the partition P, of figure 1.

On the floor of each stimulus-box, E, are electrodes by means of which electric shocks may be given as punishment for failures to distinguish and properly to react to the two stimuli. The doors F, F, leading from the stimulus compartments into the alleys G, G, may be raised by the experimenter by means of the cords shown in the figure. When the subject enters the compartment which contains the stimulus selected by the experimenter as the positive stimulus, the appropriate door F is immediately raised, the slide-door, H, of the same side opened, and the subject thus permitted to pass by way of the alley G, back to the starting point at A, where is it allowed to feed for a definite interval. In case, however, the subject enters the other compartment, it is not allowed to pass into the alley, but instead, either with or without the use of the electric shock, according to the experimenter's previous decision, it is required to retrace its steps and again attempt to distinguish the stimulus which demands positive reaction from that which demands negative reaction.

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[3] Watson, J. B. Behavior. New York, 1914, p. 70.

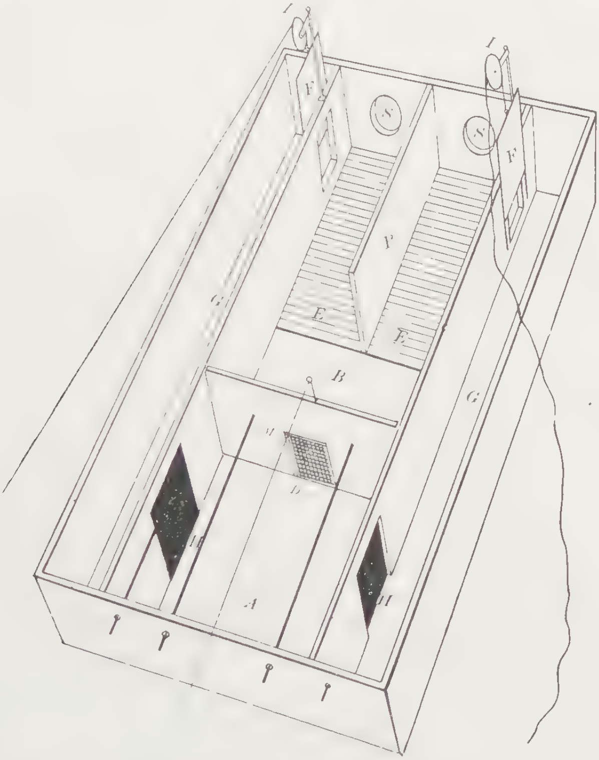

FIG. 1. Reaction-box for Ring-doves. A, entrance chamber; B, discrimination compartment; D, screen-door; M, sliding partition moving in A and B; E, E, stimulus compartments; P, partition between E and E; F, F, doors between stimulus compartments and alleys G, G,; H, H, slide-doors between G and A; I, I, pulleys for cords attached to F, F; S, S, stimulus apertures.

In the case of the observations about to be described, achromatic stimuli were obtained by placing a two candle power carbon incandescent lamp 86 cm. from the stimulus area. Thus, the one of the stimulus areas presented to the subject was always illuminated, whereas the other was entirely unilluminated, except as general illumination was employed in the experiments. Naturally, as the experiment-box was shifted from side to side, the more intense achromatic stimulus was presented now in the stimulus compartment on the right of the subject, now in the one on the left.

The writer is convinced that wherever possible the interference of the experimenter in the course of an animal's reaction should be obviated by the use of automatic or subject-actuated devices. It was not feasible, however, in the present investigation, to introduce such devices,—consequently the use of the slide-doors, as shown in figure 1. These, it should be stated, proved surprisingly satisfactory in the case of the ring-dove, which is easily startled and which would not react well in a subject-actuated apparatus unless everything could be made to work steadily, quietly, and fairly slowly. It is, however, beyond question that our efforts in studies of behavior should be to eliminate, as far as possible, the necessity, during the course of reaction, of movements by the experimenter which tend to modify the behavior of the subject. It has repeatedly appeared that even the experienced investigator is liable, unconsciously, to supply cues to his subject which facilitate proper reaction, or even serve as the sole basis for what appears to be discrimination.

The birds used for the present work were obtained from a Boston dealer. All that could be learned about them was that they were young We are therefore under the disadvantage of being unable to give a satisfactory description. It is obviously desirable in all such investigations that the origin and exact age, as well as the sex and history of each subject, should be known. But this is somewhat less essential, it must be admitted, in the case of preliminary observations than in that of continuation-work. Four birds were used. Of these, two, supplied as male and female by the dealer, in reality both males, appear as numbers 1 and 2 in this report. They were used over a period of several weeks by Mr. A. M. Eisenberg. The others appear as number 3, a female, and number 4, a male. During a period of five months these birds were used in the visual experiment by the writer. The results obtained with numbers 1 and 2 will be presented only in contrast with those of numbers 3 and 4, since the conditions of use varied somewhat, and the experiments conducted by Mr. Eisenberg were not carried so far as those of the writer. The descriptions of general behavior in this paper will be based almost wholly upon the observations made on doves 3 and 4.

At the outset, it was assumed that the ring-dove would react satisfactorily in the discrimination apparatus, that it would exhibit a fair degree of docility, breed rapidly in captivity, be easy to handle, and endure close confinement well. It must be admitted that these assumptions have not all been justified, for the birds did not quickly adapt themselves to the experimental situations, and in docility they rank low. Indeed, their slowness in acquiring the discrimination habit demanded in this work was a great surprise to the writer. He is now somewhat uncertain as to whether it is desirable to attempt an intensive study of visual response with a subject which demands such a large amount of training.

Work was initiated by feeding the birds in the entrance chamber of the experiment-box, with all of the doors of the box open so that the subject might wander about at will. This was continued for a week, with the occasional variation of opening and closing the doors as the bird passed from compartment to compartment, so that it might become accustomed to the operating of the simple mechanisms and learn the route from the entrance chamber, by way of the stimulus chamber, back to the starting point.

During the second week of the preliminary observations, the birds were sufficiently tame and accustomed to the apparatus to work fairly well. They were regularly each morning required to make the trip through the apparatus three or four times, and they were rewarded for so doing with food. It was discovered that they would not make the trip quickly unless they were very hungry, and even in that condition their attention to the situation was very variable, and they were so easily distracted by slight noises or jars that the whole process was a very tedious one. It thus became apparent that unless an additional motive for discrimination and progress through the experiment-box could be discovered, the work would be most tedious. Consequently, at the beginning of the third week, the electric shock was introduced as a means of compelling attention to the visual stimuli and of encouraging careful comparison and appropriate reaction. Even from the start, the electric stimulus served this purpose admirably. It at once rendered the birds more alert, careful, attentive, and active. The writer's notes record, " In two weeks the doves apparently have learned nothing, but to-day as the result of four trials with electrical stimulation, each seemed to attempt to discriminate between the light and the dark chambers.

It was decided, on the basis of the preliminary observations, that the doves should be required to choose the lighter rather than the darker of the two compartments.

Number 3, the female, was at the outset much less wild and more timid than number 4, the male. It was much easier for the experimenter to catch her in the living-cage than to catch him, but when in the experiment-box, she was very much more disturbed, excitable, and liable to discouragement than he. By contrast, then, the female may be described as tame and timid. the male as wild and bold. But it should be added that neither bird was sufficiently wild to be difficult to handle.

On February 28th, 1914, systematic, regular experiments were begun, with the use of both food and the electric shock. Both birds worked well in the six trials which were given. Only one bird was used at a time, and it was given its trials in succession, with from one-half to one minute interval for feeding between choices. In comment on this day's reactions, the writer's notes state that " The use of the electric shock discreetly and infrequently has transformed the birds from time-wasting and careless subjects to active, alert, constantly moving reactors. This modification of method evidently means a saving of an immense amount of time to the experimenter. It enables him to command the attention of his subject instead of having to beg for it by the offering of food. Food, however, is serving an excellent purpose in the work, for each bird comes to its task hungry and usually feeds between trials."

On March the 2nd, the number of trials for each bird was increased to ten, and it was subsequently found that as many as fifteen or even twenty trials could be given in succession without overfatiguing the subjects and with excellent results.

Table 1 presents two sample detailed records of the daily trials from the writer's note-book. The first portion of the table gives the results of an early series of ten choices, those of March 4th. The remainder of the table presents, by contrast, the results of a later series of fifteen trials in which the birds were practically perfect in their discrimination. This series was given on April 19th. The table indicates, in the first column, the position of the positive stimulus, that is the stimulus indicative of the chamber to be entered. In the second column, the letters R and W designate, respectively, correct and incorrect choices.

TABLE 1

Examples of Detailed Daily Records

March 4, 1914, 10:10 A. M. With general illumination. Stimulus-lamp 86 cm. from stimulus area. Coil at 1 cm. for female and 2 cm. for male.

		Female, No. 3		Male, No. 4	
Trial	Positive stimulus	Reaction	Remarks	Reaction	Remarks
1	Left	W	Shocked?	W	Shocked?
2	“	W	“	W	“
3	“	W	“	W	Shocked
4	Right	R	Direct	W	“
5	Left	W	Shocked?	R	Discrimination
6	Right	R		R	Anxious
7	“	W		R	“
8	“	W	Shocked	R	Eager
9	Left	R		W	No shock
10	Right	W		W	Shock
Summary:		4 R:6 R		4 R:6 W	

April 19, 1914, 9:50 A. M. With general illumination. Stimulus-lamp 126 cm. from stimulus area. Coil at 2 cm. for both.

		Female, No. 3		Male, No. 4	
1	Left	R	Near-mistake	R	Exc. disc.
2	Right	R	Direct	R	
3	“	R	“	R	
4	“	R	“	R	
5	“	R	“	R	
6	Left	R	“	R	
7	“	R	Good disc.	R	
8	“	R	“	R	
9	“	R	Near-mistake	R	Careful
10	Right	R	Eager	R	
11	Left	R		R	
12	Right	R	Direct	R	
13	“	R	“	R	
14	Left	R	Near-mistake	R	
15	“	W	Careless	R	
Summary:		14 R:1 W		15 R:0 W	

TABLE 2

Summary of Results of Training in Light-dark Discrimination.
Electrically Illuminated Area Versus Unilluminated Area.
Electric Shock Used as Punishment.

Dove Number 3, ♀				Dove Number 4, ♂			
Date	Conditions	Right	Wrong	Date	Conditions	Right	Wrong
Feb. 28	Gen. ill., elect. stim....	3	3	Feb. 28	Gen. ill., elect. stim....	4	2
Mar. 1	No gen. ill., elect. stim.	3	3	Mar. 1	No gen. ill., elect. stim.	4	2
“ 2	“ “ “ “ “	8	2	“ 2	“ “ “ “ “	5	5
“ 3	Mixed illum., “ “	9	1	“ 3	Mixed illum., “ “	5	5
“ 4	Gen. illum., “ “	4	6	“ 4	Gen. illum., “ “	4	6
“ 5	“ “ “ “	6	4	“ 5	“ “ “ “	6	4
“ 6	“ “ “ “	4	6	“ 6	“ “ “ “	7	3
“ 7	“ “ “ “	4	6	“ 7	“ “ “ “	6	4
“ 8	“ “ “ “	6	4	“ 8	“ “ “ “	4	6
“ 9	“ “ “ “	3	7	“ 9	“ “ “ “	5	5
“ 10	“ “ “ “	6	4	“ 10	“ “ “ “	7	3
“ 11	“ “ “ “	5	5	“ 11	“ “ “ “	4	6
“ 12	Mixed gen. ill. “ “	4	6	“ 12	Mixed gen. ill. “ “	9	1
“ 13	“ “ “ “	6	4	“ 13	“ “ “ “	8	2
“ 14	Gen. illum., “ “	5	5	“ 14	Gen. illum., “ “	8	2
“ 15	“ “ “ “	3	7	“ 15	“ “ “ “	6	4
“ 16	No. gen. ill., “ “	4	6	“ 16	No gen. ill., “ “	6	4
“ 17	Gen. illum., “ “	5	5	“ 17	Gen. illum., “ “	5	5
“ 26	“ “ “ “	3	7	“ 26	“ “ “ “	5	5
“ 27	“ “ “ “	9	1	“ 27	“ “ “ “	5	5
“ 28	“ “ “ “	4	6	“ 28	“ “ “ “	4	6
“ 29	“ “ “ “	6	4	“ 29	“ “ “ “	5	5
“ 30	“ “ “ “	4	6	“ 30	“ “ “ “	5	5
“ 31	“ “ “ “	4	6	“ 31	“ “ “ “	5	5
Apr. 1	“ “ “ “	11	4	Apr. 1	“ “ “ “	5	10
“ 2	“ “ “ “	9	6	“ 2	“ “ “ “	5	10
“ 3	“ “ “ “	8	7	“ 3	“ “ “ “	13	2
“ 4	“ “ “ “	9	6	“ 4	“ “ “ “	9	6
“ 5	“ “ “ “	8	7	“ 5	“ “ “ “	8	7
“ 6	“ “ “ “	12	3	“ 6	“ “ “ “	10	5
“ 7	“ “ “ “	9	6	“ 7	“ “ “ “	9	6
“ 8	“ “ “ “	11	4	“ 8	“ “ “ “	11	4
“ 12	“ “ “ “	11	4	“ 12	“ “ “ “	14	1
“ 13	“ “ “ “	13	2	“ 13	“ “ “ “	14	1
“ 14	“ “ “ “	14	1	“ 14	“ “ “ “	13	2
“ 15	“ “ “ “	10	5	“ 15	“ “ “ “	13	2
“ 16	“ “ “ “	12	3	“ 16	“ “ “ “	14	1
“ 17	Stim. less, “ “	11	4	“ 17	Stim. less, “ “	15	0
“ 18	“ “ “ “	13	2	“ 18	“ “ “ “	14	1
“ 19	“ “ “ “	14	1	“ 19	“ “ “ “	15	0
“ 20	“ “ “ “	12	3	“ 20	“ “ “ “	14	1

The general results of the several series of reactions required for doves number 3 and number 4 appear in table 2, under their appropriate dates. A brief statement is given in the second column of the table of the important conditions of reaction. It is stated, for example, whether general illumination was used

TABLE 3

Summary of Results of Training in Light-dark Discrimination. Electrically Illuminated Area Versus Unilluminated Area. Electric Shock Not Used

Dove Number 1, ♂				Dove Number 2, ♂			
Date	Conditions	Right	Wrong	Date	Conditions	Right	Wrong
Mar. 2	Gen. illum	3	7	Mar. 3	Gen. illum	2	3
“ 3	“ “	5	5	“ 4	“ “	2	3
“ 4	“ “	4	6	“ 7	“ “	2	3
“ 7	“ “	1	4	“ 9	“ “	2	3
“ 9	“ “	2	3	“ 10	“ “	2	3
“ 10	“ “	0	5	“ 11	“ “	2	3
“ 11	“ “	3	2	“ 12	“ “	2	3
“ 12	“ “	3	2	“ 13	“ “	0	5
“ 13	“ “	3	2	“ 14	“ “	2	3
“ 14	“ “	4	1	“ 16	“ “	2	3
“ 16	“ “	0	5	“ 17	No gen. illum	1	4
“ 17	No gen. illum	1	4	“ 18	“ “ “	2	3
“ 18	“ “ “	1	4	“ 19	“ “ “	2	3
“ 19	“ “ “	1	4	“ 20	“ “ “	1	4
“ 20	“ “ “	2	3	“ 21	“ “ “	2	3
“ 21	“ “ “	1	4	“ 23	No gen. ill., elect. stim.	1	4
“ 23	No gen. ill., elect. stim.	2	3	“ 24	“ “ “ “ “	2	3
“ 24	“ “ “ “ “	2	3	“ 25	“ “ “ “ “	1	4
“ 25	“ “ “ “ “	3	2	“ 26	“ “ “ “ “	5	5
“ 26	“ “ “ “ “	2	3	“ 27	“ “ “ “ “	4	6
“ 27	“ “ “ “ “	2	3	“ 28	“ “ “ “ “	4	6
“ 28	“ “ “ “ “	3	2	“ 30	“ “ “ “ “	4	6
“ 30	No gen. illum	4	6	“ 31	“ “ “ “ “	5	5
“ 31	“ “ “	5	5	Apr. 1	Gen. illum	5	5
Apr. 1	Gen. illum	2	8	“ 2	“ “	5	5
“ 2	“ “	6	4	“ 3	“ “	6	4
“ 3	“ “	1	9	“ 4	“ “	7	3
“ 4	“ “	4	6	“ 6	“ “	4	6
“ 6	“ “	8	2	“ 8	“ “	6	4
“ 8	“ “	5	5	“ 9	“ “	4	6
“ 9	“ “	5	5	“ 10	“ “	4	6
“ 10	“ “	2	8	“ 11	“ “	5	5
“ 11	“ “	5	5	“ 13	“ “	6	4
“ 13	“ “	5	5	“ 14	“ “	5	5
“ 14	“ “	4	6	“ 16	“ “	5	5
“ 17	“ “	7	3	“ 17	“ “	5	5
“ 18	“ “	5	5	“ 18	“ “	7	3
“ 20	“ “	2	8	“ 20	* “	4	6
“ 21	“ “	3	7	“ 21	“ “	7	3
“ 23	“ “	10	0	“ 23	“ “	3	7
“ 24	“ “	6	4	“ 24	“ “	10	0
“ 25	“ “	1	9	“ 25	“ “	5	5
“ 27	“ “	10	0	“ 27	“ “	9	1
“ 28	“ “	10	0	“ 28	“ “	6	4
“ 29	“ “	10	0	“ 29	“ “	9	1
“ 30	“ “	10	0	“ 30	“ “	5	5
May 9	“ “	6	4	May 1	“ “	6	4
“ 11	“ “	9	1	“ 2	“ “	10	0
“ 14	“ “	6	4	“ 2	“ “	10	0
				“ 4	“ “	10	0
				“ 9	“ “	9	1
				“ 11	“ “	8	2
				“ 14	“ “	5	5

or not, and it is indicated that in a few series of observations the conditions of illumination were mixed, that is, for some of the reactions general illumination was employed, whereas in others it was lacking. Throughout the regular experiments the electric stimulus was employed. On April 17th, as is indicated, the intensity of the visual stimulus was lessened, thus diminishing the difference in the stimuli to be distinguished.

Table 3 presents the comparable results for doves number 1 and number 2. The chief difference in the conditions for these results and those obtained with doves numbers 3 and 4 is the absence of the electric stimulus in the case of the former. With the exception of one week, March 23rd to March 28th, Mr. Eisenberg trained number 1 and number 2 to achromatic discrimination on the basis of food as a reward without the use of the electric shock as punishment for mistakes. His results, therefore, may be compared with those of the writer, with a view to discovering the value of punishment as contrasted with reward in this experiment with ring-doves.

Such comparison indicates, in the first place, that it is possible to make a larger number of observations per series with punishment than without it. Thus, the writer by the aid of the electric stimulus was able to make ten, fifteen or even twenty observations per series. Whereas, Mr. Eisenberg, without the electric stimulus, could not satisfactorily make more than ten observations, and during a considerable portion of the training he made only five. Second, the time required for the work varied much more widely when punishment was not used than when it was used. As appears from tables 2 and 3, all of the doves acquired the ability to discriminate with a reasonable degree of certainty, and to react appropriately. The course of habit formation in case of each of the four subjects is surprising. Instead of being steady, regular, and fairly rapid, as the writer had anticipated, it proved to be irregular and extremely slow. One day the experimenter would feel confident that his subjects were acquiring the habit, and the next day he would find them utterly unable to react properly.

In table 4 the choices are presented by groups of fifty, and the course of habit formation is indicated with the daily variations eliminated. This table shows that as the result of three hundred trials, no one of the four doves had acquired the ability

TABLE 4

REACTIONS IN LIGHT-DARK TRAINING GROUPED IN FIFTIES TO SHOW SLOWNESS OF IMPROVEMENT AND IRREGULARITIES

Trials	Dove 1, ♂		Dove 2, ♂		Dove 3, ♀		Dove 4, ♂	
	Right	Wrong	Right	Wrong	Right	Wrong	Right	Wrong
1 -50	18	32	18	32	32	18	27	23
51–100	18	32	20	30	23	27	29	21
101–150	22	28	21	29	23	27	35	15
151–200	23	27	28	22	25	25	25	25
201–250	20	30	25	25	27	23	22	28
251–300	25	25	26	24	30	20	29	21
301–350	37	13	36	14	34	16	34	16
351–400	36	9	41	9	41	9	46	4
401–450			27	8	38	12	47	3
451–500					30	5	33	2

to react properly. Between the three hundredth and the four hundredth trials, all of them, however, showed marked improvement. Were it not that two experimenters were involved and the conditions of observation thoroughly controlled, it might fairly be suspected that the doves finally discovered some other basis for reaction than the difference in the intensity of illumination. We are convinced, however, that this was not the case and that the results satisfactorily prove that the ring-dove is extremely slow, under the conditions described, in learning to react appropriately to achromatic stimuli, even though they differ very markedly. It must be admitted, however, that there are certain features in table 3 which are puzzling. Number 1 discriminated perfectly on April 23rd, and number 2 on April 24th, whereas on both the preceding and the following days they did poorly. This suggests to the writer that they had happened upon some means of choosing other than that intended by the experimenter.

From a careful comparison of the data of tables 2, 3, and 4, it is clear that by the use of the electric stimulus, it is possible to develop a visual discrimination habit in the dove much more quickly, and consequently with less labor, than by the employment of the food getting desire alone.

All of the foregoing observations are merely preparatory to the work with chromatic stimuli. It therefore seems unnecessary to burden the reader with further details of conditions or results, except possibly with respect to the general illumination and its relation to the reactions. In some of the series, general illumination was not employed, and it was naturally apparent that the doves could distinguish the stimuli much more easily than when the surroundings were illuminated. It was deemed desirable to use general illumination in order to guard against choice on the basis of the visibility of the sides and floor of the stimulus chambers, for naturally enough, this differed greatly in the light and the dark chambers in the absence of general illumination. On the whole, it seemed very much more satisfactory to conduct experiments in the general illumination produced by a two candle power frosted carbon incandescent lamp, at a distance of 110 cm. above the center of the partition beween the stimulus chambers.

As an aid to rapid reaction, the alleys of the experiment-box were kept dark except at the moment of entrance of the dove. In each alley was placed a low-power lamp which could be turned on the instant the door F was raised, and turned off the instant the door H was opened. This served to induce the dove to enter the alley-way and to hasten through it to the food-box. After a few daily series, the birds made the trip quickly and voluntarily, seldom loitering in the passageways and usually passing from entrance chamber to discrimination chamber rapidly.

The food placed in the entrance chamber as a motive for return to that portion of the experiment-box was milk-soaked bread, with a small quantity of cracked corn added. During a large portion of the series, the birds ate little, unless they were practically deprived of food while in the living-cage. It is thus fair to say that the process of habit formation in the case of doves 3 and 4 depended almost solely upon punishment, whereas the process in the case of birds 1 and 2 depended solely upon reward.

As in the writer's previous use of punishment, the induced current was used by means of a Porter inductorium with a number 6 Columbia dry cell as source of current. In the early experiments, no attempt was made to keep the feet of the birds moist, and as a consequence, the secondary coil had to be placed well over the primary. Its position was varied somewhat from day to day, but in general it was placed at 1 cm. for the female and at 3 cm. for the male. This, of course, means that the male responded to a very much weaker electric stimulus than did the female, but it is probable that this indicates not so much a difference in sensitiveness to the stimulus as the result of difference in weight, for the male bird was much heavier than the female. During March it was found difficult to get satisfactory responses, even when the maximum current was used, and the experimenter finally hit upon the device of placing a square piece of moist blotting paper before the food-box in the entrance chamber. This was found to yield very satisfactory results. The secondary now had to be set at 2 cm. for the female and $2\frac{1}{2}$ for the male. The settings proved satisfactory throughout the remainder of the work, and whereas previously the responses to the electric stimulus had varied extremely, they subsequently were very constant.

RESULTS WITH CHROMATIC STIMULI

Doves 3 and 4, having been trained to practically perfect discrimination of a bright area from a dark area of the same size, were tested for preference of spectral red and green. The value of the red stimulus was 626 to $640\mu\mu$, while that of the green was 498 to $510\mu\mu$. In energy, as measured by the selenium cell, the red stood slightly above the green, but they were so nearly the same that it seemed needless to attempt to equate them more closely for these preliminary experiments.

Table 5 presents in summary the results of the chromatic reactions of doves 3 and 4. From this table it appears that on April 21st, when given an opportunity to choose either the red or the green chamber, without punishment, number 3 chose the one as often as the other, whereas number 4 chose the red eight times, the green twice. On April 22nd, in the absence of general illumination and with a period of two minutes for darkness adaptation before the series was commenced, the results were entirely different, for number 3 selected the green nine times out of ten, while number 4 chose it five times out of ten. On the following day, the original conditions of April 21st were reinstated and the responses were similar to those of that date. On April 28th, by the elimination of general illumination, darkness adaptation was effected, and the results again, as on April 22nd, favored the green.

TABLE 5

Results of Experiments with Chromatic Stimuli

Dove Number 3, ♀				Dove Number 4, ♂			
Date	Conditions	Red	Green	Date	Conditions	Red	Green
Apr. 21	Preference for red or green........	5	5	Apr. 21	Preference for red or green........	8	2
“ 22	“ “ “ .... (darkness adaptation)	1	9	“ 22	“ “ “ .... (darkness adaptation)	5	5
“ 23	“ “ “ .... (gen. illum.)	3	7	“ 23	“ “ “ .... (gen. illum.)	7	3
“ 28	“ “ “ .... (no gen. illum.)	4	6	“ 28	“ “ “ .... (no gen. illum.)	5	5
Apr. 29	Red-black training....	11	9	Apr. 29	Red-black training....	18	2
“ 30	“ “	16	4	“ 30	“ “	12	8
May 1	“ “	13	7	May 1	“ “	18	2
“ 2	“ “	13	7	“ 2	“ “	19	1
“ 3	“ “	10	10	“ 3	“ “	20	0
“ 4	“ “	17	3	“ 4	“ “	20	0
“ 5	“ “	18	2	“ 5	“ “	17	3
“ 6	“ “	17	3	“ 6	“ “	19	1
“ 7	“ “	19	1	“ 7	“ “	19	1
“ 8	“ “	18	2	“ 8	“ “	17	3
May 9	Red-green training....	14	6	May 9	Red-green training....	16	4
“ 10	“ “	10	10	“ 10	“ “	20	0
“ 11	“ “	10	10	“ 11	“ “	15	5
“ 12	“ “	13	7	“ 12	“ “	16	4
“ 13	“ “	15	5	“ 13	“ “	15	5
“ 14	“ “	13	7	“ 14	“ “	13	7
“ 15	“ “	14	6	“ 15	“ “	17	3
“ 16	“ “	14	6	“ 16	“ “	13	7
“ 17	“ “	14	6	“ 17	“ “	16	4
“ 18	“ “	13	7	“ 18	“ “	15	5
“ 19	“ “	16	4	“ 19	“ “	18	2
“ 20	“ “	16	4	“ 20	“ “	18	2
“ 21	“ “	15	5	“ 21	“ “	19	1
“ 22	“ “	17	3	“ 22	“ “	19	1
“ 23	“ “	14	6	“ 23	“ “	14	6
“ 24	“ “	14	6	“ 24	“ “	16	4
“ 25	“ “	18	2	“ 25	“ “	17	3
“ 26	“ “	18	2	“ 26	“ “	18	2
“ 27	“ “	20	0	“ 27	“ “	18	2
“ 28	“ “	20	0	“ 28	“ “	20	0

From these four series of ten reactions with doves numbers 3 and 4, it may be inferred that under the condition of general illumination in which these doves had been trained to distinguish the light stimulus patch from the dark and to react positively to the lighter of the two, the spectral red and green stimuli appeared of about the same intensity to the female dove, whereas to the male, the red appeared the more intense. One naturally infers that both birds, as a result of their previous training, would go to the stimulus patch which appeared the lighter of the two, supposing that an appreciable difference existed. The series of observations on April 22nd and 28th with darkness adaptation indicate that green appeared considerably lighter for both birds than without adaptation. Green was chosen more frequently by number 3 than by number 4, apparently because the two stimuli were of more nearly the same value in general illumination for this bird than for the male.

From these few observations, and naturally only a few observations could be made of preference, we may conclude that spectral red and green stimuli of approximately the same energy values did not appear markedly different to the female dove in general illumination, whereas without general illumination the green seemed the more intense. For the male, on the contrary, the red seemed somewhat more intense than the green, and darkness adaptation rendered the two of practically the same intensity.

Hess[4] has already demonstrated the Purkinje phenomenon in chickens and doves, by a method radically different from that of the writer, while Lashley[5] has more recently demonstrated it in the game bantam by the method of this investigation. There seems to be no reason for doubting that the observations described above also constitute a satisfactory demonstration of the modification of stimulating value by adaptation.

A series of observations was now instituted, beginning on April 29th, on the development of the ability to distinguish red from black and of the habit of reacting positively to red and negatively to black. Supposing that red appeared light and black dark, it would seem that both doves, merely as the result of their light-dark training with colorless stimuli, should select red uniformly and avoid the black. The results, however, as they appear in table 5, do not wholly justify this expectation.

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[4] Hess, C. Untersuchungen über das Sehen und über die Pupillenreaction von Tag- und Nachtvögeln. *Archiv. fur Augenheilkunde*, 1908, Bd. 59, S. 143.
————————. Vergleichende Physiologie des Gesichtssinnes. Jena, 1912, Bd. 4, S. 9.

[5] Watson, J. B. Behavior. New York, 1914, p. 350.

Instead, they seem to indicate that for the female dove, the red was so dark that it tended to be confused with the black, or at least was not accepted as the equivalent of the light area which the bird had previously learned to choose.

In this red-black training, it was possible to give each dove twenty trials in succession. As a result of one hundred and forty trials, number 3 was reacting properly ninety per cent of the time. Curiously enough, the male, number 4, chose the red eighteen times out of twenty in his first series, and showed throughout his reactions, in the red-black training, ability to respond to these two stimuli much as he had to the light and dark achromatic stimuli. This is, of course, wholly in agreement with the results of the preference tests, which clearly indicated that the red stimulus for some reason possessed a higher stimulating value for the male than for the female.

It is, of course, impossible to say, on the basis of the red-black results, that either bird responded to the chromatic difference instead of to the intensity difference of the stimuli. It is doubtless safer to assume that the latter alone was the basis of choice.

Beginning on May 9th both doves were presented with the red and green stimuli which on April 21st had been offered as a basis for preference reactions, with the difference that now they were required to choose the red and to avoid the green on penalty of electric stimulation. Again, each daily series consisted of twenty successive trials. The female exhibited, at first, slight ability to distinguish the two stimuli and to respond appropriately, but after three hundred and eighty trials, she was reacting perfectly. The male, on the contrary, reacted perfectly even from the first, his second series of twenty trials including no mistakes. It is thus fairly clear that he responded to the intensity difference of the two chromatic stimuli, and it seems wholly probable, in view of the gradual development of the habit, that she also acquired the ability to respond to the same difference.

From these preliminary observations, it seems safe to conclude that for the ring-dove a red and a green from the spectrum of the carbon arc, of the wave lengths designated above, and of approximately the same energy, as measured by the selenium cell, are sufficiently unlike in stimulating value to be readily distinguished by certain individuals and with difficulty by others. The particular results in hand suggest that the red has a higher stimulating value for the male than for the female.

The next step in the experiment would naturally enough have been observation of the responses of the subjects to varied energy values (intensities) of the two chromatic stimuli. Unfortunately, the investigation had to terminate at the end of May and the laborious preparation for these final observations was unavoidably wasted. The writer had fully expected and hoped, within the period of six months at his disposal when the investigation was undertaken, to ascertain whether the ring-dove can distinguish a red from a green stimulus throughout a wide range of energy or intensity values. This he did not succeed in doing, and consequently this report must be entitled " Preliminaries to a study of color vision in the ring-dove."

The principal conclusions which may safely be drawn from these observations have been suggested in the course of the presentation, but by way of summary and review, they may be enumerated here.

1. It is fairly obvious that the ring-dove is not sufficiently docile to be an ideal subject for the study of color vision by means of the method which Watson and I have developed.

2. It is indicated that the value of a certain red and a certain green may be very different for two ring-doves, and it is possible that this difference is correlated with sex, the red having a higher stimulating value for the male than for the female.

3. As has already been demonstrated by the writer in the case of a number of animals, the use of the electric stimulus as a means of compelling attention to an experimental situation and of promoting habit formation is desirable in work with the ring-dove.

4. Ring-doves differ markedly in temperament. The pair used by the writer throughout this work presented differences which must be considered if one is to understand the results. To begin with, the male was somewhat wild, but at the same time fairly bold, whereas the female was tamer but more timid. Because of this contrast in timidity, the male almost from the start proved the better subject. He was not so easily disturbed or distracted, reacted therefore more steadily, and chose more certainly. With constant handling he became quite as tame as

the female and lost almost entirely his timidity in the apparatus. She, however, continued to be rather timid throughout the several months of work, although she was perfectly tame. The differences in the nature of the reactions, as recorded in the experimenter's record-book, can be appreciated only in the light of these temperamental facts.

The sex contrasts indicated in the above paragraphs one dare not emphasize very strongly on the basis of observations on two individuals, but they at least suggest the desirability of further study of the sexes. It is the writer's opinion that they agree sufficiently closely with the results obtained in the case of other animals to justify their provisional acceptance.

As has been repeatedly noted with other animals, there are good and bad days in experimental work with ring-doves,—days which are good or bad, not, so far as one may tell, because of variation in the experimenter or his manipulation of the apparatus, but chiefly because of variations in the condition of the subjects. The experiments described in this paper were made at about the same hour each morning, and it was quite impossible for the experimenter to predict the outcome of a series in the light of previous series, for the attention of the doves to the situation seemed to vary independently of any conditions or group of conditions which the experimenter could take into account. There are animals which can be relied upon to work steadily and fairly predictably. The ring-dove is not one of them.

The writer has been led to reflect, because of the outcome of this series of observations, on the possible relation of the simplicity of the experimental situation to the results. He was compelled to devote several weeks to the establishment of a simple habit in two ring-doves, a habit which was next to valueless except as a preparation for further observations. It is natural that during this long period of preparation he should frequently wonder whether the desired end might not be gained more quickly by a different method. It seems probable that a complex situation would have proved more favorable, and that had the two stimuli varied in other respects than in intensity, the animal's attention would more readily have been directed to them and more steadily held upon them. The matter is mentioned here because it is obviously of extreme importance to students of behavior to discover the most efficient means of developing preparatory habits in animals.

In concluding this paper, the writer can not refrain from calling attention to the waste of time which results from the sacrificing of trained animals at the end of an investigation. It should be possible, through exchange, to make the same subject serve in various experiments. And different experimenters, supposing our methods to be reasonably standardized, might study quite different problems on the basis of similar preparatory habits. Thus, for example, the doves which in this investigation have been trained to certain visual reactions, might perfectly well be employed for other forms of visual response, or even to greater advantage for studies of the relation of the central nervous system to the acquired responses. It is suggested, therefore, that American investigators who are actively engaged in studies in animal behavior keep in close touch and develop a system of reporting their experiments while in progress, which may serve as a basis for the serviceable exchange of trained subjects. The writer happens to have on hand at the moment of writing three tame crows which are highly trained in certain modes of response. The labor of taming and training them would have to be valued at several hundred dollars. It is impossible, under present conditions, to make use of these birds, and unless some other investigator can be found who can take advantage of this preparation, they will have to be either set at liberty or otherwise sacrificed.

THE BEHAVIOR OF BROOK TROUT EMBRYOS FROM THE TIME OF HATCHING TO THE ABSORPTION OF THE YOLK SAC

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WITH FOUR FIGURES

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A. INTRODUCTION

Although certain senses of mature fishes have been carefully studied, little work has been done upon the reactions of embryos. The investigations of the adult fish have been made chiefly with reference to the senses of smell, taste, sight, and hearing. Herrick ('03) found that some fishes possess taste buds located in the skin, by which they habitually discover their food, while other fishes have the sense of taste confined to the mouth. That the catfish has a true olfactory sense, which is distinct from gustatory, was shown by Parker ('10). The sense of hearing has also been studied by Parker ('05, '08, '11), who believes that some fishes are stimulated by sounds of slow vibration. Bernoulli ('10), on the other hand, maintains that the fishes with which he worked do not hear, but respond through tactual and visual stimulation, when at all, to the mechanical motion of the water.

The work of Paton ('07), who describes some of the reactions of fish embryos, is of particular interest. He believes that the early attempts of fish embryos to lie upon the ventral side are not due to the influence of the nervous system, but rather to the position in which they lie in the egg, and the shape of the body, combined with the propulsion of the water. Even embryos of thirteen and fourteen millimeters show a tendency to right themselves when they swim.

This author found that trout embryos of fifteen millimeters often swam once or twice around a dish five centimeters in diameter, but in all fishes progression was possible long before this, even at nine or ten millimeters. Squeezing or pricking the yolk sac of the trout caused exaggerated movements in the young fish. The head was found to be less sensitive to touch than the body; the eye in all stages examined was rather insensitive to touch. Prompt and unmistakable responses to thermal stimuli appeared at an early age. The rate of the heart beat at ten millimeters was twenty-five or twenty-eight, and at fifteen millimeters was seventy-five or eighty.

Since the information concerning the reactions of fish embryos is so meagre, it seems desirable that the kinds of stimulation to which various types of fish react, and the age at which such reactions begin, should be ascertained and possible applications to economic problems considered. The present paper is an attempt to give a connected account of the life activities of the Brook Trout, *Salvelinus fontinalis*, from the time of hatching to the absorption of the yolk sac.

The Brook Trout is usually found in clear, cold spring water, and prefers brooks or streams flowing over gravelly bottoms. It pushes from the rivers into the smaller streams, seeking the head-waters, where it rests in the deep pools and eddies. Under natural conditions it is seldom found in water over 60° F. to 65° F. The Brook Trout spawns in autumn as the temperature of the water falls. The season, which usually lasts about two months, begins earlier in the northern latitudes, in the Lake Superior region in September, or even in August, while in New York, New England, and Lower Michigan, it commences about the middle of October. The time necessary for developing the eggs is dependent upon the temperature of the water, varying from about 125 days at 37° F. to about 50 days at 50° F.

The experiments here described were performed in the Zoological Laboratories of the University of Wisconsin. About five hundred embryos were used, eggs being obtained at the Madison Fish Hatchery, and brought to the laboratory in four different batches, so that embryos of various stages could be observed at the same time. The youngest stages were kept in a wire tray in a trough of running water (from Lake Mendota) while the older individuals were placed in glass dishes and set in running water to keep them cool. About one hundred Rainbow Trout, *Salmo irideus*, of two different stages and a number of young German Brown Trout, *Salmo fario*, which swam freely in the trough, were kept under observation.

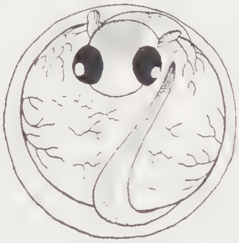
During the experiments the temperature of the water ranged from 5° C. to 10° C. Most of the experiments were performed in a dark room, the temperature of which was usually about 19° to 20° C. The fish were handled with a feather or with a spoon made of bent wire with netting stretched across it. Although there was a high rate of mortality (due to gas-bubble disease, fungi, algae which crept into the gills, and persistent handling), several of the Brook Trout survived during the whole period. All experimental data refer to the Brook Trout unless otherwise stated.

This work was accomplished under the direction of Professor A. S. Pearse, for whose helpful suggestions and encouragement it gives me great pleasure to express my appreciation.

B. EXPERIMENTS AND OBSERVATIONS

1. *Hatching*

The egg of the Brook Trout is small and nearly colorless, measuring about four millimeters in diameter. The embryo, which is about three times as long as the diameter of the egg, lies curled around its yolk sac with the tip of the tail beside the head. The eyes and head are visible through the thin shell. The hatching is initiated by movements starting at the head and later extending through the whole length of the body, so that the position of the embryo in the egg is somewhat changed. Such movements continue at intervals, varying from a quarter of a minute to an hour or more, until the shell is so strained that a slit appears. There does not seem to be any distinction as to which part of the embryo comes out first, for in the twenty-three cases observed, eight embryos appeared head first, one tail first, and in fourteen cases the yolk sac broke through before the body. The final shedding of the egg case is sometimes brought about by a violent movement of the body, but in nearly all the instances observed it was a gradual process lasting from three-quarters of an hour to five or six hours, during which the initial slit was slowly enlarged by the rhythmical motions of the body and the respiratory movements. If the anterior end is to be the first to appear, the violent contraction of the embryo raises the head until the strain splits the shell far enough to free the region bearing the pectoral fins, which immediately begin to move. The front of the head soon follows. Whether the tail or the yolk sac comes out first, the length of time required is



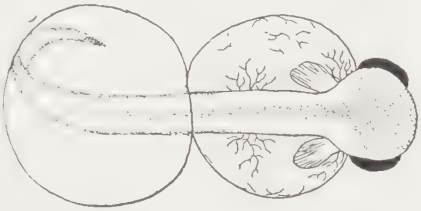


FIG. 1. Egg of a Brook Trout shortly before hatching. Magnified six and two-third times. (Drawn by Miss Wakeman)
FIG 2. Embryo hatching head first. Magnified six and two-third times

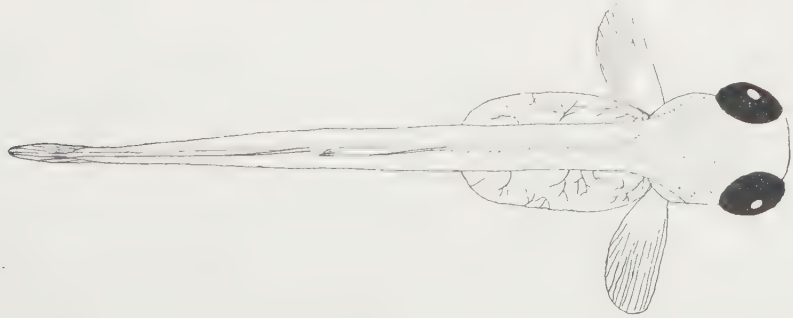


FIG. 3. Dorsal view of an embryo three weeks old (15 mm.). Magnified six and two-thirds times

nearly the same, and the details of the process differ very little. Unless the animal is disturbed, it may lie quiet for hours while the egg case slips off, but if the fish is jarred, a violent contraction almost invariably results, thus hastening the loss of the egg case. In nature, where there are great numbers of fish hatching simultaneously, they undoubtedly touch one another continually, shortening the time required for hatching.

The Brook Trout makes its appearance as a pretty, delicate, translucent creature about twelve centimeters long. Its most conspicuous features are its enormous eyes, which occupy almost the whole head, its huge yolk sac covered with a fine network of bloodvessels leading to the heart, the beating of which can plainly be seen. Along the back is a strip of pigment extending from the head to the tip of the slender tail.

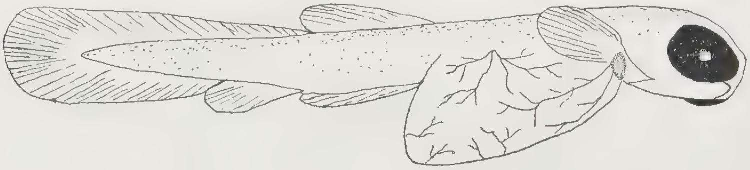


FIG. 4. Lateral view of an embryo three weeks old. Magnified six and two-thirds times

2. *Swimming Movements*

Although the Brook Trout spends most of the first six weeks of its larval life lying quietly on its side, it is perfectly capable of swimming as soon as the egg case is lost. In fact, Paton ('07), who worked on trout among other varieties of fish, states that definite progression is possible when the embryo is nine or ten millimeters long. In the present experiments, if a fish which had just hatched was suddenly touched, it would whirl round and round as if its cumbersome yolk sac formed a movable pivot. By the fourth day the movements are still rotatory, but the fish swim in larger circles and can go straight ahead for a greater distance. There is also more darting about, the tail being always the most active part of the body. The trout which is one week old (14-1.5 millimeters) swims in a spiral course. As the yolk sac diminishes in size, the fish is better able to control its movements. It lies upon its ventral side like an adult at the age of six weeks in most cases, and in swimming, continually darts about, turning first one way, then the other.

3. *Reaction to Mechanical Jars*

Possibly the first stimulus to which a developing trout reacts is that of mechanical jars. Often before the embryo has completely left the shell, the shaking of the dish or currents in the water cause it to contract, and if the tail is free, to swim about with the head still encased. This sensitiveness to mechanical vibrations continues throughout the larval life. Even so slight a vibration as that caused by blowing on the water makes the fish dart about.

4. *Reactions to Touch*

The sense of touch is well developed when the trout hatches, but it is impossible to predict what response will be given to a stimulus in any particular part of the body. Embryos in nearly all stages of development from the time of hatching until the yolk sac was lost, were touched systematically with a slender, pointed stick, and with bristles to determine whether one part of the body was more sensitive than another. I found, as Paton ('07) did, that although it is very difficult to localize the tactile areas, the head is much less sensitive than the body, and the eye is quite insensitive. Judged by such responses, the tail seems to be the most sensitive part of the body. It was found that the trout avoided a brush much more vigorously than they did a pointed stick or a single bristle. This is probably because the brush stimulates them at more points.

If touched persistently the embryos swim about, turning rapidly in all directions. When they are eventually fatigued, the responses become less marked, the trout may then merely move its tail or increase the rate of movement of its fins. It may even become absolutely quiet for a time, after which the reactions take place as before. The young trout show some measure of adaptability, for they grow somewhat accustomed to being handled, and particularly in the case of the oldest fish (three months old), those which had been repeatedly picked up were slightly easier to catch than those which had never been touched.

5. *Reactions to Current*

Since Brook Trout live in swift flowing streams, one would expect them to react to currents. In order to test this matter, a trough was constructed in which they could be tested. The apparatus was fifty inches long by two and one-fourth inches wide and three inches deep with straight sides. A piece of rubber tubing connecting with a faucet was attached to the center of one end, in such a way that a current of uniform intensity flowed through the whole length of the trough; at the other end, was an outlet covered with netting to prevent the loss of the fish.

After testing various strengths of current, the one which brought about the greatest number of reactions was found to be that which carried carmine solution the length of the trough in half a minute. Therefore, this strength of current was used in most of the experiments. Since all tests were made in a dark room, it was a simple matter to turn on the faucet a certain distance with the room in total darkness, in that way eliminating all reactions to light. Nevertheless, since it was found that the daylight had little effect on the results, the room was not darkened for all the experiments.

Nearly all stages of young Brook Trout from the time of hatching to the absorption of the yolk sac were tested. Table 1 shows some of the results.

TABLE 1

Showing the Reactions of Brook Trout to Current

Number of experiment	Number of fish used	Age of fish	Condition of light	Number of fish positive	Number of fish negative	Number of fish indifferent	Per cent of fish positive
1	25	4 days	day	22	0	3	88%
2	25	4 days	dark	21	0	4	84%
3	20	34 days	day	17	0	3	85%
4	20	42 days	day	16	0	4	80%
Total percentage of Brook Trout reacting positively................							84.25%

The fish were placed in the trough one at a time in most cases, with right and left sides alternately toward the current before the water was turned on. The fact that the older trout showed a slightly smaller percentage of positive reactions is probably not significant, as there appears to be no difference in their reactions, except such as would be caused by their greater activity and strength. Although it is not recorded in table 1, embryos which had just been hatched were found to react positively to current. But they were usually unable to swim more than a few centimeters, or able merely to orient themselves, owing to the size of the yolk sac.

While none of the Brook Trout were persistently negative in their reactions to current, there were always a few which did not give a definite positive response. Since it was noted that a fish was sometimes carried backward farther than it was able to advance, the four embryos in experiment number two which did not react definitely were tested later in the light, where they could be watched. One fish did not swim at all. Three fish were carried backward, but oriented toward the source of the current. They struggled to advance, but were unable to do so. Therefore, these were actually positive.

Of the twenty-one which are marked positive, five were evidently weak; their condition somewhat resembling the three just mentioned. Since these were found on being tested in the light to be clearly positive, and on the third trial in the dark progressed decidedly toward the current, they were included with the trout which had just been observed to move definitely against the current.

In order to discover whether surrounding objects affect the reaction to current, a striped paper was passed back and forth, beneath and at the sides of the glass dish containing Brook Trout about three weeks old. No reaction resulted. Brook Trout were also placed in a round glass dish set within another dish and a current of water made to run between the dishes. To this also the fish failed to react. Hence during the first few months, the sense of sight appears to have little or no relation to the reaction of Brook Trout to current. This does not agree with what Lyon ('04) believed to be true regarding the fishes with which he worked.

Positive rheotropism was also exhibited by a school of German Brown Trout two or three months old, that were almost invariably found resting or swimming about near the source of the current in the trough where they were kept. On testing Rainbow Trout three days old, when the yolk sac is enormously large, forty or fifty per cent were observed to be positive to current, while sixty per cent were indifferent, the latter either lying quiet or whirling about without orienting themselves when stimulated.

6. *Reactions to Light*

That young Brook Trout are negatively phototropic has been recognized by the fish-hatchers who, finding that the trout seek the dark corners, keep the troughs covered. Their phototropism, however, was tested more accurately in the following manner: A Nernst lamp was placed within a large box (75 cm. wide x 120 cm. long x 120 cm. high) blackened inside and out, and having an opening (6 cm. x 9 cm.) at one end. A narrow glass dish, 4 cm. through, containing water was placed before the hole to absorb the heat rays; at right angles to this was an oblong glass dish with rectangular sides (38 cm. long x 10 cm. wide x 8 cm. high) in which the fish were placed.

Brook Trout of nearly every age, from those which had just hatched to those two months old, were placed in the dish singly or in groups and left for varying lengths of time. Table 2 shows the results.

TABLE 2

SHOWING THE LIGHT REACTIONS OF BROOK TROUT

Age of trout	Number of trout	Strength of light	Number of trout negative	Number of trout positive	Number of trout indifferent	Per cent of trout negative	Per cent of trout positive	Per cent of trout indifferent
2 days	25	1.5 candle meters	14	0	11	56%	0	44%
2 days	25	2.3 candle meters	21	2	2	84%	8%	8%
2 days	5	7.7 candle meters	4	0	1	80%	0	20%
21 days	10	2.3 candle meters	7	2	1	70%	20%	10%
21 days	10	7.7 candle meters	8	0	2	80%	0	20%
21 days	10	16 candle meters	8	2	0	80%	20%	0
Totals.....	85		62	6	17	75%	8%	17%

In the experiments tabulated the trout were placed in the center of the dish with right and left sides alternately toward the light, so as to eliminate complication from a propensity to turn toward a particular side of the body. Each fish was observed for five minutes. The strengths of the lights given are approximately what the fish actually encountered in the center of the dish. It may be noted that a somewhat greater percentage reacted negatively to a light 2.3 candlemeters than to a light 1.5 candlemeters. Above 2.3 candlemeters, however, the increase in the strength of light seems to make little difference. Brook Trout less than a week old in general react more strongly to a weak light (2.3 candlemeters) than to a strong one (16 candlemeters). With the older fish this does not seem to be true.

The conclusion that young Brook Trout larvae are negatively phototropic was corroborated by other incidental observations. When a dish containing fish was placed before a window, they almost invariably sought the side of the dish away from the light. The same was true of the Rainbow Trout.

In order to discover whether a Brook Trout is photokinetic, a Nernst lamp was suspended about eighteen inches above a dish containing them. When the light was first turned on, the trout darted about vigorously, many seeking the corners of the dish. After a few minutes' exposure, however, they came to rest quietly as before. The same experiment was tried with Rainbow Trout with like results. It was observed that the raising of a window curtain suddenly allowing the sunlight to fall on a dish of Rainbow Trout, stimulated them to unusual activity for several minutes.

From these experiments it is evident that Brook Trout are photokinetic and negatively phototropic.

7. *Light and Current*

It has been shown that Brook Trout are negative to light and positive to current. It is desirable to know how they react when the two stimuli conflict. Fish-hatchers claim that when a light is placed at the head of the current, the trout go away from the light, thus reversing the usual reaction to current. In order to study this matter, the trough used for the current experiments was entirely covered except for an opening 3 cm.

x 4 cm. at the end where the water entered. Opposite this opening was placed a Nernst lamp having an intensity of about ten candlemeters in the center of the trough.

Trout about one week old were placed in the center of the trough, four at a time in most instances, since the trough was found to be large enough to hold that many without interference. Their positions were noted just before the water was turned on and again five minutes later. Twenty-five Brook Trout were used. Of these twenty-three moved away from the light and two fish did not change their positions.

This seems to show that Brook Trout become negative to current when a light is placed at the head of the stream. This probably means that in natural conditions, when they have to choose between shelter and cool water, they seek shelter.

8. *Carbon Dioxide and Light*

Since an excess of Carbon Dioxide is a condition which a growing fish is likely to meet, the way in which a Brook Trout responds to it and the effect it has upon its light reactions is very important in determining whether or not the trout is to escape from the unfavorable conditions, and swim into purer water, where there is more oxygen.

For the purpose of discovering the effect of an excess of carbon dioxide upon the response to light, fifty individuals were tested separately in the apparatus used for the light experiments in a five per cent solution of carbonated water.[1] The strength of the light for one-half the fish was two candlemeters, for the other half about eight candlemeters. The results of the two were similar.

Almost immediately after a trout was placed in the carbonated water, the fins began to move more rapidly and the mouth to open and close with a gulping motion. Shelford ('14) describes this same condition in the fish that he tested in an excess of carbon dioxide. In the present experiments, the trout were stimulated to great activity, swimming continually from one end of the dish to the other with no apparent reference to the light. They were as likely to stop at the end of the dish toward the light as at that away from it. Excess of carbon dioxide apparently causes the Brook Trout to be indifferent to light.

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[1] The solution of carbonated water was made by adding carbonated water from a siphon to the ordinary city water, which is taken from Lake Mendota.

A ten per cent solution of carbonated water was also tried, but this was found to partially anesthetize the Brook Trout in from three to five minutes, and therefore no reactions resulted. The young trout were able to endure a five per cent solution for two or three hours without apparent injury; at the end of such a period of time they seemed somewhat sluggish. A two and a half per cent solution also had a stimulating effect. A twenty or twenty-five per cent solution caused all swimming movements to stop almost immediately, and made the heart beat of a trout three weeks old fall within about eight minutes from an average of eighty beats a minute to thirty-seven. Death ensued very soon after that. This was tried in several other cases with similar results.

9. *Reaction to Shadows*

As was stated in the discussion of rheotropism, the Brook Trout three weeks old does not respond to moving objects outside the water. This seems to be true of objects in the water also, provided they do not cause mechanical jars. This absence of reaction to shadows continues until the embryo is about six weeks old, when the greater part of the yolk sac is absorbed. At this time the trout suddenly begin to respond; the waving of a hand above the dish causes them to dart about in all directions. If such a movement is made repeatedly, however, they soon become accustomed to it and cease to react for a time.

The reaction to shadows is, therefore, not present at hatching, but becomes apparent at the time when the yolk sac is greatly reduced in size and shortly before the feeding reactions begin. It would be interesting to know whether there is a change in the eye or the nerve connections at this period, which brings about this new response, or whether it is merely due to increased swimming power.

10. *Feeding Reactions*

The feeding reactions begin when the Brook Trout are about two months old. At this time the larvae appear to develop a sudden curiosity concerning everything about them. They swim to the top more frequently and often explore the bottom. The fish studied were fed liver chopped very fine and put into the water with a dropper. For several days the trout did not appear to notice it, at least they were not observed to eat. A stream of meat juice directed against the body was avoided in the same manner as a jet of clean water. After a week or less, however, the trout began to take bits of food into their mouths as they chanced upon them and often to swallow them. From this time on they were observed to dart after pieces of meat floating about in the water, although they often rested directly upon meat lying on the bottom without appearing to pay any attention to it. They were also seen to chase bubbles and bits of filter paper, and to take them into their mouths, but they never swallowed them. The fish were fed in dishes with black or white bottoms. The trout were found to take food more eagerly from the dishes with black bottoms where the food was more plainly visible, although they would also eat pieces of meat over the white backgrounds. This fact is made use of by the fish-hatchers who feed the larvae in blackened troughs.

In order to discover what part is played by the chemical sense in helping the Brook Trout to find its food, a bag containing meat was placed in the water; this was nosed by the trout and one fish bit at it. At other times two bags, one with food and one without it, were set in the dish. The trout investigated both bags, but they bit at neither. They were apparently unable to discover meat hidden under a paper in the bottom of the dish. Although they wandered over it as they swam about, it was not noted that its presence had any effect upon the fish.

The Brook Trout apparently first react through sight to the presence of food, since they were often observed to leave pieces of meat near them to dart after bits farther away, which would not be the case, were it the chemical sense which was most strongly stimulated. The gustatory sense appears to determine whether or not the food is swallowed.

C. GENERAL DESCRIPTION OF THE EARLY LIFE OF THE BROOK TROUT

Let us follow a developing Brook Trout on the pebbly bottom of a swift flowing stream. During the first six weeks of its existence it does not move far from the spot where it was hatched, but lies quietly in the shadows among the stones, out of sight of its enemies. It is not affected by objects passing over head.

If someone throws a stone into the water the jar startles the little fish into swimming about rapidly for a few seconds, after which it sinks again into some shady nook. Here it rests, until a sudden eddy caused by an animal swimming through the water, makes it dart a few inches into the current. Other tiny fish touch and jostle it continually. If the water becomes filled with carbon dioxide, it becomes more active, and overcoming its impulse to avoid the light, swims about restlessly from place to place until it comes into purer water, where it again sinks down beneath the stones. Thus far its responses have been largely avoiding reactions, serving to keep it from unfavorable conditions.

When the trout is about six weeks old, it becomes more sensitive to objects outside itself. The sight of other animals passing by sends it scurrying under the cover of moss and stones. Shortly after this it begins to be curious, nosing nearly every object which it sees. It swims to the top of the water in pursuit of a bubble. It explores the bottom of the stream, often swimming head downward, passing in and out among the rocks, stones, and algae. Many particles on the bottom or floating above are taken into the mouth. If found to be good to eat, they are swallowed; if not, they are expelled. As the fish eats, it takes food more and more eagerly until it is satisfied, when it ceases to react, and hides in the algae.

Throughout its larval life the Brook Trout is reacting to external and internal stimuli, responding to nearly every current, object, or ray of light that strikes it.

In general, the behavior suits the needs of the fish. As long as the trout are very young, and are encumbered with the large yolk sac, which renders them unable to swim any distance, their reactions are such as would naturally tend to keep them lying quietly out of the sight of their enemies. They exhibit no curiosity, but avoid the light, hiding beneath the rocks and stones, reacting to current just enough to keep them from being carried down stream. The trout appear not to notice external objects, except as their approach jars the fish, making them struggle to regain their equilibrium.

As was previously stated, an excess of carbon dioxide renders them temporarily indifferent to light, so that they swim about restlessly until they reach a place where the water is purer.

When the Brook Trout grow larger, lose the yolk sac, and become strong enough to escape their enemies by swimming away, they begin to notice moving objects inside and outside of the water. The approach of any object sends them darting about in all directions in search of a hiding place. Just before the trout are old enough to commence eating, they show great interest in every object in the water, and begin to try taking any small object from a bubble or a bit of alga to a piece of meat into their mouths, though they appear to swallow only such as are edible.

From the consideration of the facts of behavior one is naturally led to ask what are the artificial conditions which best suit the needs and instincts of the young trout. In other words, what is the economic importance of the experiments discussed in this paper. One easily concludes from the observation of the natural conditions of Brook Trout and their reactions to current and carbon dioxide, that the first essential is cool running water with plenty of oxygen. The water should be free from algae of a sort which is apt to get into the gills. If a fungus attacks the young trout, the disease spreads rapidly, unless the infected and dead fish are removed, since the fish knock against each other as they swim about.

The fact that Brook Trout are so strongly negative to light seems to indicate that hatching troughs should be covered, or if the fish are in ponds or streams, that the trout should have natural covers, such as rocks, stones, or water plants, under which to hide. By living beneath these they may often escape predaceous animals which prey upon them.

Since it requires nearly a week for Brook Trout to learn to eat, they should be carefully watched when they are near the feeding stage, for if they do not learn to take food before the yolk sac is entirely absorbed, they will die of starvation. Shortly before the trout are two months old, they commence to swim to the top frequently and to exhibit curiosity, which indicates that they will soon begin to eat. Meat ground or chopped very fine should then be introduced into the water, so that the fish may take particles of it into their mouths by chance, as they wander about, and thus become accustomed to it before it is necessary for them to eat.

D. SUMMARY

1. The Brook Trout which has just hatched swims with a whirling movement. About the fourth day after hatching, the trout commences to swim in a spiral course, and from then on, the movements become gradually better co-ordinated, the trout swimming in larger circles and going straight ahead for greater distances.

2. The Brook Trout reacts to touch and mechanical jars immediately after hatching. The head is the least sensitive to touch of any part of the body, the eye being insensitive. The reaction is more marked when the trout is stimulated at a number of points, than when it is touched with a single bristle.

3. Positive rheotropism becomes apparent as soon as the trout has hatched.

4. The Brook Trout is photokinetic and negatively phototactic.

5. Directive light from a lamp at the source of the current reverses the usual rheotropic reaction, showing that Brook Trout are more strongly negative to light than they are positive to current.

6. An excess of carbon dioxide up to a certain point stimulates Brook Trout; a very strong solution depresses them. A five per cent solution stimulates trout to move about continually and makes them indifferent to light. Stimulation is also brought about by a two and a half per cent solution. A twenty or twenty-five per cent solution causes a rapid fall in the rate of the heart beat, then death.

7. Brook Trout begin to respond to shadows about the fifth week after hatching, when the yolk sac is greatly diminished in size.

8. Feeding reactions commence when Brook Trout are about two months old. The sense of sight seems to cause the trout to take small objects into the mouth, the gustatory sense to decide whether or not they are edible.

9. Before the yolk sac is absorbed the reactions of the young trout are protective, afterward they are exploratory and aggressive.

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THE EARTHWORM AND THE METHOD OF TRIAL

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About ten years ago Jennings attempted to clarify existing conceptions of the behavior of the lower organisms by substituting for what he believed to be an inadequate theory of tropisms a conception that rested on what has come to be known as the "method of trial."

Tropism hypotheses have existed at various times that have differed in various respects. There is no doubt that in one respect or another, some of these hypotheses have been open to just criticism. That the method of trial affords an escape from such criticism, however, is becoming less and less apparent with the passage of time.

Notwithstanding their differences, all tropism hypotheses agree in excluding the conception of orientation by trial reactions. Fundamental to them all is the conception of orientation by means of movements that, with reference to a given source of stimulation, are *predictable* as to direction. However cogent, then, the criticism of a particular variety of tropism hypothesis in other respects, it can hardly affect the fundamental characteristic which they all possess in common.

Some months ago, an analysis of the behavior of *Porcellio scaber* showed that the method of trial was incompetent to interpret the orientation of this organism under photic stimulation.[1] In the present paper we shall consider the orientation, under similar stimulation, of the earthworm (*Allolobophora* sp.), an organism of some complexity of structure, whose behavior has seemed to some observers to lend support to the method of trial. These critics have based their conclusions in part on observations,[2] in part on the identification of "random" with

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[1] Torrey and Hays. The Rôle of Random Movements in the Orientation of *Porcellio scaber* to Light. *Jour. Animal Behav.*, 1914, **4**, p. 110.

[2] See especially Holmes. The Selection of Random Movements as a Factor in Phototaxis. *Jour. Comp. Neur. Psych.*, 1905, **15**, p. 98.

"trial" movements, a source of confusion that has already been discussed in the paper on *Porcellio* to which we have just referred.

The earthworm comes midway between the sow bug (*Porcellio*) and the leech in the freedom with which it bends its body when reacting to light. It has been shown[3] that the first movements of *Porcellio* after stimulation are away from the source of light. The body moves stiffly as a whole. The photoreceptors are anteriorly placed paired eyes. Holmes cites observations on the leech *Glossosiphonia* that show a wide range of mobility in its response to light, dependent upon its characteristic locomotion. The earthworm does not react stiffly, like *Porcellio*, nor are more than a very few anterior segments concerned in whatever random movements may be observable under photic stimulation. Holmes was led to believe that the method or orientation of the leech is, in principle, the same as that of the earthworm. He calls especial attention to the characteristic waving of the body, preliminary to fixation of the anterior end. Our observations, however, encourage us to place emphasis on the resemblance of the reactions of the earthworm to the behavior rather of *Porcellio* than of *Glossosiphonia*. The random movements of the earthworm have thus appeared to us to be less significant elements in its orientation to light than the observations of Holmes indicated.

It is characteristic of the earthworm when advancing in diffused light, to protrude its anterior end first on one side and then on the other, with successive extensions, in fairly regular alternation. A distinct tendency thus exists for this end, when bent to one side, to bend to the opposite side at the next extension. Mechanical causes, such as tensions in muscles and skin, are probably responsible for it. It is natural to expect evidence of this tendency in experiments on earthworms where relatively low intensities of light are employed unilaterally. Mast, indeed, asserts that in active worms, " the anterior end is simply turned sharply in the direction opposite to that in which it is when it receives the stimulus. . . . Thus it is turned toward the light about as often as from it, regardless of the light intensity."[4] Sluggish individuals, however, reacted quite differently.

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[3] Torrey and Hays, 1914.

[4] Light and the Behavior of Organisms. 1910, p. 200.

From what we judge to have been a neutral position, six sluggish individuals, in one hundred and fifty trials, turned toward the light in but ten of them. In certain other cases there "was no evidence of even the slightest preliminary turning toward the source of light." (P. 201.)

From this evidence ours differs in that our active individuals behaved in the low intensities of light used very much like the sluggish individuals of Mast. Whatever the ultimate significance of this distinction, we have been forced to conclude, as Mast appears to have concluded, that under some conditions, earthworms respond to photic stimulation by orienting reactions that are in no sense trial or random movements. Nevertheless, in our figures, there was unmistakable evidence of that tendency which has been mentioned of the anterior end to swing from side to side. This did not appear, however, in our first series of experiments.

In our first series, sixteen active individuals, taken from darkness, were each subjected to one hundred exposures in quick succession to a very low light intensity. The worm under observation crawled over a moist slate. When, in very weak diffused light, the anterior end was pointed straight forward, the light of a small pocket lamp was flashed upon it from a distance of 50 mm. at an angle of ninety degrees with the body axis. The results are shown in the accompanying table.

From these figures it appears that our earthworms exhibited a marked disposition to react without trial negatively to the light used.

Our second series of observations was taken under somewhat different conditions, and shows very clearly the tendency to which we have alluded above. Each of ten worms was subjected to a total of but thirty trials, in groups of ten. In the first ten trials, the anterior end was bent toward the light at the instant the light was flashed; in the second ten it was in a neutral position, that is, directed forward; in the third ten, it was bent away from the light. Each worm was rested for about seven minutes in darkness after each group of ten trials. A light of slightly greater intensity was used, namely, a 25 w. Mazda lamp, 160 mm. distant, so screened that the ray falling on the worm was about 8 mm. wide. In other respects, the conditions were essentially the same as in the first series.

TABLE 1

	No. of trials	Direction of first movement	
		Toward light	Away from light
Earthworm No. 1	100	18	82
“ 2	100	22	78
“ 3	100	18	82
“ 4	100	28	72
“ 5	100	16	84
“ 6	100	26	74
“ 7	100	34	66
“ 8	100	14	86
“ 9	100	24	76
“ 10	100	28	72
“ 11	100	12	88
“ 12	100	32	68
“ 13	100	20	80
“ 14	100	21	79
“ 15	100	43	57
“ 16	100	34	66
Totals	1600	390	1210
Percentages	....	24.4%	75.6%

TABLE 2

	No. of trials	Position of anterior end with reference to light					
		Toward		Neutral		Away	
Sense of response	....	—	+	—	+	—	+
Earthworm No. 1	30	9	1	8	2	9	1
“ 2	30	8	2	9	1	9	1
“ 3	30	8	2	9	1	7	3
“ 4	32	10	0	10	1	8	3
“ 5	30	10	0	9	1	7	3
“ 6	30	10	0	8	2	9	1
“ 7	30	10	0	8	2	8	2
“ 8	30	10	0	9	1	9	1
“ 9	30	10	0	8	2	10	0
“ 10	30	10	0	9	1	9	1
Totals	302	95	5	87	14	85	16
Percentages of first movements away from light	....	95%		86.13%		83.16%	

Assuming now, the observed tendency of the anterior end to swing in fairly regular alternation from side to side in successive extensions; and assuming, further, the tendency brought out by the figures just given, for the anterior end to swing directly away from the light; one should expect to find the anterior end swinging away from the light *most* frequently, in this second series, when it was turned *toward* the light at the instant the latter was flashed, and *least* frequently when it was turned *away* from the light at the moment of flashing.

This expectation is, in fact, realized in the following figures. The light was flashed on the right of the first seven individuals, on the left of the others.

The third double column of figures is especially significant, as it shows a very marked negative reaction of the worms observed, under the conditions of the experiment, in spite of the conflicting tendency manifested in diffused light to swing the anterior end in the opposite direction.

Holmes has pointed out the danger of failing to notice certain very inconspicuous movements that might be started *toward* the light but not followed up. We have tried to guard against this opportunity for error. At the same time, it may be worth while to remark that a certain degree of extension of the anterior segments appears to be necessary to expose the photoreceptors to effective light intensities. Our figures seem to us to show clearly that photic stimulation, far from inducing random movements, immediately calls forth reactions in a definitely predictable direction. In the face of the facts, a view based upon minute random movements that are not referable to photic stimulation can hardly affect the conclusion that the earthworm must be placed, with *Porcellio*, in that group of organisms whose orientation to light is determined essentially by movements that are predictable as to direction and hence neither random movements nor " trials."

ELIMINATION OF ERRORS IN THE MAZE[1]

HELEN B. HUBBERT

While engaged in a research problem on the learning ability of white rats at different ages, my attention was directed to the question of the elimination of useless movements in the learning of the maze. I decided to test whether or not such eliminations occur progressively, i.e., whether useless movements most closely connected with satisfaction (food) are the first to drop out, while the useless movements most remote from the source of satisfaction (food) persist the longest.

The observations recorded in this paper were made on four groups of rats of different ages during their learning of the Watson maze which, with its camera lucida attachment, is described at length in a previous number of this journal.[2] The process of training and the criteria of learning were the same as those set forth in a previous paper.[3]

As has been pointed out by Watson,[4] according to the pleasure-pain hypothesis, the inference of progressive elimination is plain. Food (the "satisfier") is at the center of the maze. Errors in the alley nearest the food should be the first eliminated; those in the alley next nearest, second, and so on until we reach those in the first alley (the one farthest from the food). Errors in this alley should be the ones last eliminated.

An examination of the plan of the maze will show that in every alley except VI there are three possibilities of error, viz.:

1. Taking the wrong turn at the alley entrance.
2. Going too far in the alley, i.e., past the entrance to the next alley.
3. Taking the correct turn, but returning ("doubling" on the pathway).

In VI the first error is impossible because there is no stop, and either turn leads to the food box. The second error resolves itself into a circling of the food box, which, however, rarely occurs.[5] The third error is the most common one. Starting to the right, the rat retraces its path and goes to the left, or vice versa. Clearly then, the sixth alley is not strictly comparable with the others, and should not be considered. It is therefore set off from the rest in the accompanying tables.

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[1] From the Psychological Laboratory of The Johns Hopkins University.

[2] Watson, J. B. *Journal Animal Behavior*, vol. IV, p. 56.

[3] Hubbert, H. B. *Ibid*, pp. 60-62.

[4] Watson, John B. Behavior. Holt & Co., p. 268.

In the first alley the emotional disturbance of the animal is very great. Whether he will turn to the right or to the left is a matter of pure chance. Watson has shown that the learning of the maze is due largely to the kinaesthetic and organic impulses which cannot begin to play their rôle very effectively until some distance has been run in the maze.[6] As stated above, the start in the first alley is as likely to be in the wrong as in the right direction. If the start is wrong increasing disturbance ensues, and is often carried over into alley II.[7] Aside from this fact, there is the very strong tendency to back-track to the point of entrance (E), which has a different stimulating value from any other part of the maze. It is for these reasons that the first alley as well as the sixth is judged incomparable with the rest and hence is set off from them in the tables.

This leaves for consideration four alleys, II, III, IV and V. Whether the process in question is spoken of as the elimination of errors, the "stamping in" of useful movements and the "stamping out" of useless ones, or simply as the *elimination of alleys* matters little; the facts remain the same. The writer has chosen for convenience to speak of the elimination of superfluous movements in an alley as the elimination of the alley itself, and the results are so tabulated. For example, Rat 4 of Group A made its last error in alley II at the 11th trial, running the alley perfectly in all succeeding trials. The alley is therefore spoken of as eliminated at the 12th trial. Likewise III was eliminated at the 8th trial, IV at the 3rd and V at the 7th trial, no errors being made in those alleys after the 7th, 2nd, and 6th trials respectively. The first column gives the laboratory number of the animal, while column 2 gives the total number of trials the animal required to learn the maze.

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[5] This error seldom occurs, because in passing the entrance to the food box the smell and sight of the food become directive.

[6] Watson, J. B. Kinaesthetic and Organic Sensations—Their Rôle in the Reaction of the White Rat to the Maze. *Psychological Monographs,* Series No. 33.

[7] It is not unlikely that the deviation of the results in alley II from those in III, IV and V may be explained in this way.

In the tables, cases which undoubtedly show uniform progressive elimination, i.e., a 5-4-3-2 order, are doubly starred (**). Cases which might possibly be considered progressive are singly starred (*). Cases clearly not progressive are unmarked.

TABLE I

GROUP A—25 DAYS

Rat	Trials	Alleys					
		I	II	III	IV	V	VI
4	18	10	12	8	3	7	3
5	14	7	6	9	9	8	5
6	45	40	32	29	10	37	10
7	66	60	35	43	49	15	1
8	32	25	26	25	17	11	1
9	38	33	22	27	31	24	1
10**	28	21	22	14	8	5	9
11	18	13	12	7	2	10	5
12	32	19	27	16	17	13	1
13	46	39	38	41	13	26	1
14	24	17	17	4	3	12	2
15	34	25	13	11	1	28	4
16	27	17	14	22	5	6	1
17	26	21	13	11	6	7	19
19	40	30	33	34	30	19	5
20**	34	28	28	15	10	9	1
21	36	31	18	25	13	14	2
22	32	27	23	23	18	23	7
23	34	15	19	29	22	23	1
24	24	11	18	9	6	19	10
25	36	19	29	19	19	30	3
Totals.. 21 rats	..	508	457	421	293	346	92
Averages........	..	24	**22**	**20**	**14**	**16**	4

2 cases (**) uniformly progressive or 10%, vs. 90% not progressive.
9 cases where IV and V are eliminated before II and III, or 43%.

DISCUSSION OF THE TABLES

GROUP A—21 RATS

These rats began the problem when twenty-five days old.

Two of the twenty-one showed uniform progressive elimination, i.e., alley V was eliminated first, alley IV second, alley III third and alley II fourth and last. We find then two cases of uniform progression and nineteen cases clearly not uniformly progressive, i.e., ten per cent progressive versus *ninety per cent* not progressive.

If we now count the cases where IV and V are eliminated before II and III but not in a 5-4-3-2 order, e.g., Rats 4 and 16, we find them to be nine, or forty per cent of the group, which is less than would be expected on a chance basis.

If, however, instead of considering individual cases, we look at the averages, we still find no uniform progression. But here again IV and V are eliminated before II and III.

TABLE II

Group B—65 Days

Rat	Trials	Alleys					
		I	II	III	IV	V	VI
11	18	13	8	8	9	3	1
12	34	25	28	20	29	25	1
13**	22	9	17	10	3	1	7
14	22	16	15	15	3	7	1
15	28	19	12	22	9	9	3
16	36	30	17	9	31	16	8
17	36	30	25	16	2	26	7
18	66	61	47	24	54	33	5
19	32	26	18	4	2	8	3
20	36	31	20	9	12	9	4
21	46	41	36	37	8	8	6
22	21	15	13	6	6	8	2
23	38	31	22	33	29	26	1
24	38	33	30	15	24	28	1
25	14	9	4	5	9	3	1
27	40	35	29	12	9	25	3
28	20	15	9	10	5	4	1
Totals— 17 rats	..	439	350	255	244	239	55
Averages........	..	26	**21**	**15**	**14**	**14**	3

1 case (**) uniformly progressive or 6%,
vs.
16 cases not uniformly progressive or 94%.
5 cases where IV and V were eliminated before II and III, or 29%.

Group B—17 Rats

These animals began the problem when sixty-five days old.

Of the seventeen, one rat showed uniformly progressive elimination while sixteen did not, i.e., six per cent progressive and *ninety-four per cent* not progressive.

TABLE III
GROUP C—200 DAYS

Rat	Trials	Alleys					
		I	II	III	IV	V	VI
6	18	12	9	4	7	9	3
7	54	48	46	40	42	35	16
8	44	39	36	33	38	24	21
9	26	13	19	5	21	5	5
10	20	15	5	4	3	4	1
11	20	13	14	4	13	11	11
15	32	27	23	23	7	20	4
17	56	50	35	22	45	19	11
18	79	71	66	30	74	29	12
19	49	44	44	18	9	15	11
20*	27	22	9	8	8	8	8
21	32	26	18	7	13	12	2
23	30	25	17	25	4	22	3
24	30	25	15	13	14	9	1
25	35	26	30	9	30	8	8
27	22	11	17	9	14	6	6
29	104	99	95	74	88	88	5
30*	108	101	98	87	87	38	22
31	64	58	45	55	23	12	1
33	32	27	15	27	24	19	5
34	22	13	15	5	13	17	17
35**	37	30	30	16	13	10	2
36	32	21	8	2	8	15	26
38	14	9	7	4	4	6	1
Totals.. 24 rats	..	825	716	524	602	441	202
Averages........	..	34	**29**	**22**	**25**	**18**	8

1 case (**) or 4% uniformly progressive.
2 cases (*) or 8% doubtful.
21 cases or 88% not progressive.
3 cases or 13% in which IV and V were eliminated before II and III.

Here we find five rats eliminating IV and V before II and III, or twenty-nine per cent.

The averages show possible uniform progression, although the values for III, IV and V are too nearly identical to warrant such an interpretation.

GROUP C—24 RATS

These rats began the problem when two hundred days old.

Of them, one rat showed uniform progressive elimination, two possible progressive elimination, while twenty-one did not show such progression. Stated in percentages, four per cent were progressive, eight per cent possibly progressive and *eighty-eight per cent* non-progressive.

Here we find only three cases or thirteen per cent where IV and V were eliminated before II and III. The averages showed no progression; IV and V were not even eliminated before II and III.

TABLE IV

GROUP D—300 DAYS

Rat	Trials	Alleys					
		I	II	III	IV	V	VI
15	78	67	72	35	39	35	3
16	20	14	11	9	10	8	1
17	48	43	28	15	36	14	3
18	40	31	35	9	32	34	7
19	14	9	9	4	9	5	1
20**	58	45	52	35	28	27	5
21	30	25	12	6	9	9	13
22	82	77	67	47	64	66	66
24	42	37	33	26	25	28	34
25	54	49	27	37	49	49	37
26*	19	14	10	7	7	7	4
27*	70	65	61	24	24	22	24
28	38	33	24	20	6	24	5
30	27	22	16	15	8	13	6
31	84	78	32	53	72	69	69
33	16	11	8	5	2	11	3
34	66	60	60	25	26	48	27
35	38	32	20	19	20	17	9
36	26	15	15	5	15	11	21
37	44	39	29	17	13	30	5
38**	34	28	23	15	8	6	1
39**	35	5	29	23	21	11	4
Totals.. 22 rats	..	799	673	451	523	544	128
Averages........	..	32	**30**	**20**	**24**	**25**	16

3 cases (**) or 14% uniformly progressive.
2 cases (*) or 9% doubtful.
17 cases or 77% not progressive.
3 cases or 14% where IV and V were eliminated before II and III.

GROUP D—22 RATS

These rats began the problem when three hundred days old. Three of the twenty showed uniformly progressive elimination, two showed possible progressive elimination, while seventeen did not show uniform elimination, i.e., fourteen per cent were progressive, nine per cent possibly progressive and *seventy-seven per cent* not progressive.

There were three cases where IV and V were eliminated before II and III or fourteen per cent.

The averages do not show progressive elimination nor were IV and V eliminated before II and III.

We do find, however, in every group that alley II is nearly always the last to be eliminated. A possible explanation of this has already been offered on page 67. The results in alleys III, IV and V are so nearly identical that the three may be considered as eliminated at practically the same time.

From these experiments it seems fairly probable that the rapidity with which a given co-ordination in a complex habit is formed is not proportional to the distance from the point at which the co-ordination takes place to the point at which food is to be obtained.

NOTES

NOTE ON THE REACTION OF THE HOUSE-FLY TO AIR CURRENTS

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While making some experiments on the drying of certain vegetable materials in a current of air, the following observation was made, which may be of interest.

The material had a strong attraction for flies, of which there were several in the room, and as their presence did not interfere with the work, no precautions were taken to screen them off. The apparatus consisted of a flat bottomed aluminum dish, 20 cm. in diameter, with vertical sides 8 cm. high; into this dish was blown a current of air having a volume of about one-fourth to one-half cubic meter per minute, by means of an electric hair-drier (speed equals about 100 meters per minute). The air was slightly heated, showing 29 to 30° C., when the room temperature was 26 to 27° C. The air current struck the center of the bottom of the dish at an angle of 60°, passing over two 5 cm. aluminum dishes, in which the material being dried was contained. Flies alighting on the material in these dishes soon turned toward the direction from which the air was coming, walked down over the edge of the dish, on to the bottom of the large dish, and toward the point where the air current struck the bottom, usually stopping two or three centimeters from the center; here they would remain, with their axes parallel to the direction of the air current, and their heads facing to windward for half an hour or longer, if not disturbed. They appeared to be pressed down against the bottom of the dish by the force of the air current, quivering slightly with variations in the pressure, and they were observed not to be feeding. New comers, alighting in any other than the position above described, moved about in short jerks, until they had assumed this position. Sometimes chains of two or three, immediately back of one another, would be formed, with spaces of only a few millimeters between them, though more usually they placed themselves so as to have the head in the direct air current. Those in other portions of the dish assumed positions with the axis parallel to the stream lines, with the head to windward, even though they happened to be in a slight eddy current. A thermometer was placed in the dish, inclined toward the fan; a few insects climbed up this toward the fan, but the current appeared to be too strong for them. Increasing the temperature of the air current to 40° C. caused scattering and finally flight, though the flies seemed reluctant to go, rather attempting to back away slowly, before taking to flight. Sudden stopping of the current of air caused immediate dispersal. While most of the insects took to flight at once on being disturbed mechanically, as with the bulb of the thermometer, a few of them would allow themselves to be pushed about and even pressed down tightly on the bottom of the dish, with the thermometer bulb, without taking flight. The writer believes that the observation has been made that flies lighting on moving vehicles usually turn with the axis parallel to the direction of motion, and with the head forward, but he is not aware of any observation of the kind here recorded. Unfortunately, means were not at hand to try the effect of wider and lower variations of the temperature of the air.

FINANCIAL STATEMENT

For the information of its subscribers, contributors, and benefactors, the Journal of Animal Behavior proposes hereafter to publish, in the first number of each volume, a brief statement of its financial condition.

FINANCIAL STATEMENT FOR THE JOURNAL OF ANIMAL BEHAVIOR, DECEMBER 30, 1913 TO DECEMBER 1, 1914 (VOLUME 4)

RECEIPTS

Balance from 1913	$154.67	
Receipts from sales of complete volumes and odd numbers	786.30	
Receipts from advertising	50.00	
Gifts and contributions toward the cost of illustrations and tabular material	222.13	
Interest	27.26	$1,240.36

EXPENDITURES

Cost of manufacturing and distributing volume 4 (this does not include cost of paper, paid in 1913)	$868.48	
Office expenses, including postal and express items	180.00	1,048.48
Balance on hand		$191.88